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EMP ISOLATION PROVIDED BY LARGE FARADAY-SHIELDED TRANSFORMERS

Boeing Aerospace Company

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The pulse response of a variety of power transformers was determined, with emphasis on Faraday-shielded transformers. Tests were conducted on seven transformers and an Inductrol regulator at the SAFEGUARD North Dakota site. The transformers range in size from 10 MVA to 250 VA. The analysis program used the test results to the transformer characteristics, and to calculate the shielding effectiveness of the transformers for a variety of input conditions, loads, and wiring configurations.

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TECHNICAL MEMORANDUM

TM-82

EMP ISOLATION PROVIDED BY LARGE FARADAY-SHIELDED TRANSFORMERS

SUBMITTED BY
BOEING AEROSPACE COMPANY
SEATTLE, WASHINGTON

PREPARED FOR
U.S. ARMY ENGINEERING DIVISION, HUNTSVILLE
CORPS OF ENGINEERS
CONTRACT DACA87-72-C-0002

DECEMBER 1974

1a

ABSTRACT

The pulse response of a variety of power transformers was determined, with emphasis on Faraday-shielded transformers. Tests were conducted on seven transformers and an Inductrol regulator at the SAFEGUARD North Dakota site. The transformers range in size from 10 MVA to 250 VA. The analysis program used the test results to the transformer characteristics, and to calculate the shielding effectiveness of the transformers for a variety of input conditions, loads, and wiring configurations.

KEY WORDS

EMP
Faraday-Shield
Isolation
Regulator
Transformer

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1.0 TRANSFORMER ANALYSIS SUMMARY

1.1 OBJECTIVE

In the analysis of EMP propagation in power systems, evaluation of the isolation provided by the power transformers is required. Some major sources of EMP coupling into a power system are overhead lines, buried cables, unshielded equipment, etc. Critical areas are isolated by shields, filters, transformers, switchgear, etc. The numerical values for the EMP isolation provided by these isolation devices are needed for the calculation of EMP levels at various locations throughout the power system. The objective of this study was to determine the EMP shielding effectiveness of the types of transformers used in the SAFEGUARD System.

1.2 SCOPE

A test and analysis program was developed and completed to characterize the pulse response of a variety of power transformers, with emphasis on Faraday-shielded transformers. Tests were conducted on seven transformers and an Inductrol regulator at the SAFEGUARD North Dakota site. The transformers range in size from 10 MVA to 250 VA. Five are three-phase shielded, two are single-phase unshielded. The analysis program used the test results to determine the transformer characteristics, and to calculate the shielding effectiveness of the transformers for a variety of input conditions, loads, and wiring configurations.

1.3 APPROACH

To establish the basic approach to the determination of EMP isolation provided by large Faraday-shielded transformers, a definition of what is meant by "transformer isolation" is required, suitable test data is needed, and both input-output circuitry and disturbing pulse shapes must be specified.

1.3 (Continued)

For purposes of this study, "transformer isolation" is defined as 1) the ratio of peak-output to peak-input pulse currents under selected conditions, and 2) the ratio of peak-output to peak-input pulse voltages under selected conditions. The selected conditions involve the specification of appropriate disturbing pulse shapes, input circuits, and load

1.3 (Continued)

circuits, for a particular transformer type. It is necessary to note the possibility of obtaining widely different numerical values of isolation for different transformers for various selected conditions. Thus,one of the important aspects of this study has been the choice of the selected conditions to represent the particular applications of each transformer to yield a response matrix for those particular applications, and to establish the variability of the isolation for various parameters to permit the estimation of isolation for cases which have not been specifically evaluated.

To obtain test data, the transformers were connected in various "modes" or circuit configurations to establish two-port (black box) representations of the propagation of EMP through the transformers. Then in general, y-parameter data for these configurations were taken in the frequency domain. The frequency range used for most of the swept-cw data was 30 kH_z to 32 MH_z. Spot-cw data was obtained at 1 kH_z and 50 kH_z. Data up to 100 MH_z was obtained for one transformer.

The input and output circuits external to the transformer are represented by a resistive source impedance and a resistive load in most cases. Also the response of a system, consisting of a direct buried cable, a transformer, another cable, and a complex load, was calculated. The values of the resistive sources and loads for a particular transformer are based on calculations of the equivalent transmission-line impedance of the associated conduit, or the equivalent resistance of the associated loads. The disturbing pulses are represented as double-exponential pulses having suitable frequency content. The pulse response for each transformer and each of its selected conditions was computed using Fourier transform methods.

1.3 (Continued)

Several data processing programs were developed for reducing the transformer data. The original frequency domain-data is in terms of the magnitude of the y parameters and the associated phase. This data is digitized, then converted to ABCD parameters by the ABCDOF program. The ABCD parameters are the most useful for system calculations, since the ABCD parameters for system elements can be chained together to represent larger portions of a system. Such a calculation is shown in Appendix A. The data was originally taken in terms of y parameters because a single-point ground can be readily established for the associated measurement circuitry. The ABCDOF program produces 1024 complex numbers per parameter, to represent a particular transformer. These parameters can be stored on tape and used by the ZAPTST program to compute pulse response for the selected conditions. As an alternative, the ABCDOF output can be input to the SHAKER routine, which selects the 98 most significant complex numbers per parameter for output on cards. The accuracy of SHAKER is readily checked by comparing plots of the ABCD parameters from SHAKER with the ABCDOF output plots. The current technique for use of SHAKER (input of inverse ABCD parameters) has been found to provide excellent accuracy in most cases. The availability of the transformer ABCD parameters on cards from SHAKER has been very convenient for some applications. The SHAKER output in addition to the direct ABCDOF output, is used by the ZAPTST program to compute pulse response for the selected conditions.

1.4 ASSUMPTIONS

The approach for the determination of transformer isolation for this study rests on several assumptions which are implicit in the above discussion. The basic assumptions are:

1.4 (Continued)

1) That transformer isolation can be defined as:
   a) The ratio of peak-output to peak-input pulse currents under selected load conditions, and
   b) The ratio of peak-output to peak-input pulse voltages under selected load conditions.
2) That the double-exponential pulse, with the particular set of time constants used for this study, is a suitable representation of the threat-induced pulses.
3) That the source and load impedances can be adequately represented by selected values of resistance.
4) That the two-port configurations, or modes, properly represent the propagation of EMP through the transformers.
5) That the test-instrumentation configuration accurately measured the two-port parameters.
6) That the data-processing procedure resulted in meaningful calculations of the pulse amplitudes.

These assumptions are reasonable, and are in agreement with test results obtained at the North Dakota SAFEGUARD. Site tests were directed primarily at overall verification and were not planned to verify each assumption separately.

1.5 SUMMARY OF RESULTS

The transformers listed in table 1 were measured. The type of measurements taken and the data used for the isolation calculations also are given in this table.

The TFCP-1, 10 MVA, 115KV-4160V, 3Ø transformer was tested with the primary (Δ) terminals shorted and driven against ground with a pulse generator. The secondary (y) wires were individually loaded with 17-ohm resistors to ground. The neutral (y) was grounded.

TRANSFORMER	TYPE	MEASUREMENTS	ISOLATION CALACULATION
TFCP1	10MVA 115KV-4160V, 3φ SHIELDED,OIL	PULSE AND CW TRANSFER FUNCTIONS, COMMON TO DIFFERENTIAL MODE	DIRECT MEASUREMENT
TF12	500KVA 4160V-480V, 3φ SHILDED,OIL	CW Y PARAMETERS MODE 1,2,3,4 SHIELD CONNECTED ,DISCONNECTED	MODE 1 SHIELD CONNECTED, DISCONNECTED
TF AA/FA	300KVA 4160V-480V, 3φ SHIELDED, DRY	CW Y PARAMETERS MODE 1,2,3 SHIELD CONNECTED,DISCONNECTED	MODE 1,2,3 SHIELD CONNECTED, DISCONNECTED
TF1004	45KVA 480V-277V 3φ SHIELDED, DRY	CW Y PARAMETERS MODE 1,2,3, PULSE Y PARAMETERS, MODE 1, ILLUMINATION, SHIELD CONNECTED	MODE 1,2 SHIELD CONNECTED
TF1010	30KVA 480V-120V,1φ SHIELDED, DRY	CW Y PARAMETERS, MODE 1,2,3,5 SHIELD CONNECTED	MODE 1,2,5 SHIELD CONNECTED
CONTROL	250VA 480-120V. 1φ UNSHIELDED, DRY	CW Y PARAMETERS, MODE 1A,2A CW Z PARAMETERS, MODE 1A,2A	MODE 1A, 2A FROM Y PARAMETER DATA
T17363	50KV 14,760-120/240V,1φ UNSHIELDED, OIL	CW Y PARAMETERS MODE 3A	MODE 3A
CEA 14	1.5KVA 1φ ISOLATION, DRY	PULSE PARAMETERS COMMON MODE	——

TABLE I TRANSFORMERS TESTED

1.5 (Continued)

For the drive pulse, the observed t_p was 60 nsec, consistent with values of $f_\alpha = 8 \times 10^5$ Hz, $f_\beta = 6 \times 10^6$ Hz from the calculated Fourier transform (see Chapter 2). The peak pulse current transfer ratio was measured to be -27 dB with shield connected, and -24 dB with shield disconnected. The cw transfer function showed a pronounced resonance (minimum attenuation) at 10^6 Hz, where the attenuation was -22 dB. These values seen approximately consistent with the more detailed analysis of the other transformers. The definitions of the different configurations, or modes, are given in table 2. A total of 381 different combinations of pulse shape, input resistance, and output resistance were used in transformer calculations. Table 2 shows the values of source and load resistance which correspond to the data summary in table 3. The pulse-time constants (P5) were 4×10^6 and 5×10^8 sec^{-1} for this table.

From table 3, it can be seen that for shielded transformers, with the shield connected, and for Mode 1, which is the most pertinent mode, for the worst-case loading, the transformers provide at least 6-dB isolation for pulse propagation from Y to Δ, and at least 10-dB isolation for propagation from Δ to Y. For the nominal source and load resistances, at least 12-dB isolation for Y to Δ and at least 16-dB isolation Δ to Y is shown. For the low-impedance secondary (Y) load, at least 10-dB isolation from Y to Δ and at least 30-dB isolation from Δ to Y is found. The differential modes show significantly more isolation.

Source-impedance variations have small effect on isolation. In most cases a low-impedance source (2Ω) shows slightly less isolation (0-6 dB) than high values.

TABLE 2 DEFINITIONS OF MODES

MODE 1: COMMON MODE Δ, COMMON MODE Y, NEUTRAL GROUNDED

MODE 2: COMMON MODE Δ, COMMON MODE Y, NEUTRAL UNGROUNDED

MODE 3: DIFFERENTIAL MODE Δ, COMMON MODE Y, NEUTRAL GROUNDED

MODE 5: DIFFERENTIAL MODE Δ, DIFFERENTIAL MODE Y, NEUTRAL GROUNDED

MODE 1A: COMMON MODE PRIMARY, DIFFERENTIAL MODE SECONDARY SINGLE PHASE TRANSFORMER

MODE 2A: DIFFERENTIAL MODE PRIMARY, DIFFERENTIAL MODE SECONDARY, SINGLE PHASE TRANSFORMER

MODE 3A: COMMON MODE PRIMARY, COMMON MODE SECONDARY, SINGLE PHASE TRANSFORMER

CONDITIONS FOR DATA SUMMARY

	INPUT	OUTPUT	Z_C	Z_L
WORST CASE	Y	Δ	1Ω	∞
	Δ	Y	1Ω	∞
LOW IMPEDANCE SECONDARY	Y	Δ	2Ω	30Ω
	Δ	Y	30Ω	2Ω
NOMINAL	Y	Δ	30Ω	30Ω
	Δ	Y	30Ω	30Ω

TABLE 3 DATA SUMMARY

TRANSFORMER	MODE, SHIELD	PULSE DIRECTION		VOLTAGE ISOLATION, dB, (P5)		
		INPUT	OUTPUT	WORST CASE	LOW IMP SECONDARY	NOMINAL
TF12	1 ON	Y	Δ	-7	-12	-18
		Δ	Y	-15	-31	-19
	1 OFF	Y	Δ	-6	-11	-15
		Δ	Y	-15	-26	-17
TFAA/FA	1 ON	Y	Δ	-6	-12	-12
		Δ	Y	-10	-33*	16
	1 OFF	Y	Δ	-2	-6	-9
		Δ	Y	-3	-25*	-8
	2 ON	Y	Δ	-5	-12	-14
		Δ	Y	-9	-30*	-15
	2 OFF	Y	Δ	2	-8	-6
		Δ	Y	-4	-30*	-9
	3 ON	Y	Δ	-24	-34	-28
		Δ	Y	-29	-48*	-30
TF1004	1 ON	Y	Δ	-17	-21	-22
		Δ	Y	-16	-36*	-22
	2 ON	Y	Δ	-17	-20	-24
		Δ	Y	-17	-37*	-24
π 1004	2 ON	Δ	Y	-20	-36*	-24
TF1010	1 ON	Y	Δ	-6	-10	-16
		Δ	Y	-12	-30*	-16
	2 ON	Y	Δ	-6	-	-15
		Δ	Y	-11	-	-15
	5 ON	Y	Δ	-14	-	-32
		Δ	Y	-15	-56	-32
CONTROL	1A	HV	LV	-5		-20
	2A	HV	LV	-3	-	-16*
T17363	3A	LV	HV	+2	-6	-7
		HV	LV	-3	-30*	-10

*EXTRAPOLATION

1.5 (Continued)

To disconnect the shield shows some reduction in isolation. The possibility that the disconnected shield still provides some isolation is indicated by the low values of isolation provided by T17363 which is an unshielded transformer.

The 50 kVA, 480/277-volt Inductrol regulator was tested in a single-phase line-to-ground configuration (Mode 4A, see Chapter 2). The results are summarized in table 4. Terminals 1 and 2 are the normal ac input and output terminals, respectively. The designation imput to terminal 1, output to terminal 2 indicates pulse propagation from the normal regulator imput to its output, etc. A comparison of table 3 and table 4 indicates that the regulator provides less isolation than the shielded transformers for worst-case and nominal loads.

Sufficiently detailed data in graphic form is provided below to permit the selection of appropriate values of isolation for many specific applications. Also, values of isolation were identified which are generally applicable for a power system analysis when specific values for each special case are not desired.

For the 4160V to 480V shielded transformers, values of 10-dB isolation from 480V (y) to 4160V (Δ) and 20-dB isolation from 4160V (Δ) to 480V (y) were selected for general application. For the Inductrol regulator, a value of 20-dB isolation for both pulse propagation directions was selected for general application, since the appropriate load impedances are low.

TABLE 4 INDUCTROL REGULATOR DATA SUMMARY

	INPUT TO TERM.	OUTPUT FROM TERM.	Z_L Ω	Z_S Ω	VOLTAGE ISOLATION, dB, P5	
					BOOST	BUCK
WORST CASE	1 2	2 1	1 1	∞ ∞	-2 -5	-4 -4
LOW IMPEDANCE	1 2	2 1	1 1	1 1	-41 -41	-44 -44
NOMINAL	1 2	2 1	50 50	50 50	-10 -12	-12 -14

2.0 TEST AND ANALYSIS PROGRAM

2.1 MEASUREMENT TECHNIQUE

An example power system is shown in figure 1 to illustrate how the transformers are in the EMP flowpath from sources of pickup (enclosures, direct buried cable, etc.) to sensitive components (computers, crypto equipment, etc.). Thus, the transformer isolation for the appropriate conditions is needed to properly calculate the pulse transfer to the critical components. The transformer is considered as a four-terminal (two-port) black box (figure 2). The short-circuit admittance parameters (y parameters) were measured in the frequency domain. Figure 2 illustrates the y parameters for a two-port network, as well as the ABCD parameters and the formulations for the worst-case voltage and current-transfer ratios.

A three-phase shielded transformer provides so many terminals that to characterize such a transformer completely as an n-port network is unnecessarily complex. Consequently, certain circuit configurations (modes) have been chosen to represent the propagation of EMP through a transformer. Figure 3 shows the configuration which has been labeled "mode 1", with the corresponding measurement technique. Mode 1 represents the propagation of EMP where all three-phase lines are raised to the same voltage above ground (common-mode) at both the input and output of the transformer. For mode 1, the secondary (y) neutral has been grounded. This configuration represents the most pertinent EMP propagation mode. Figure 4 shows mode 2, where the only difference from mode 1 is that the neutral has been connected to the output terminal instead of ground. Mode 2 parameters are capacitive in the low-frequency region, simplifying the investigation of equivalent circuits for a transformer. Figure 5 shows mode 3, where the transformer

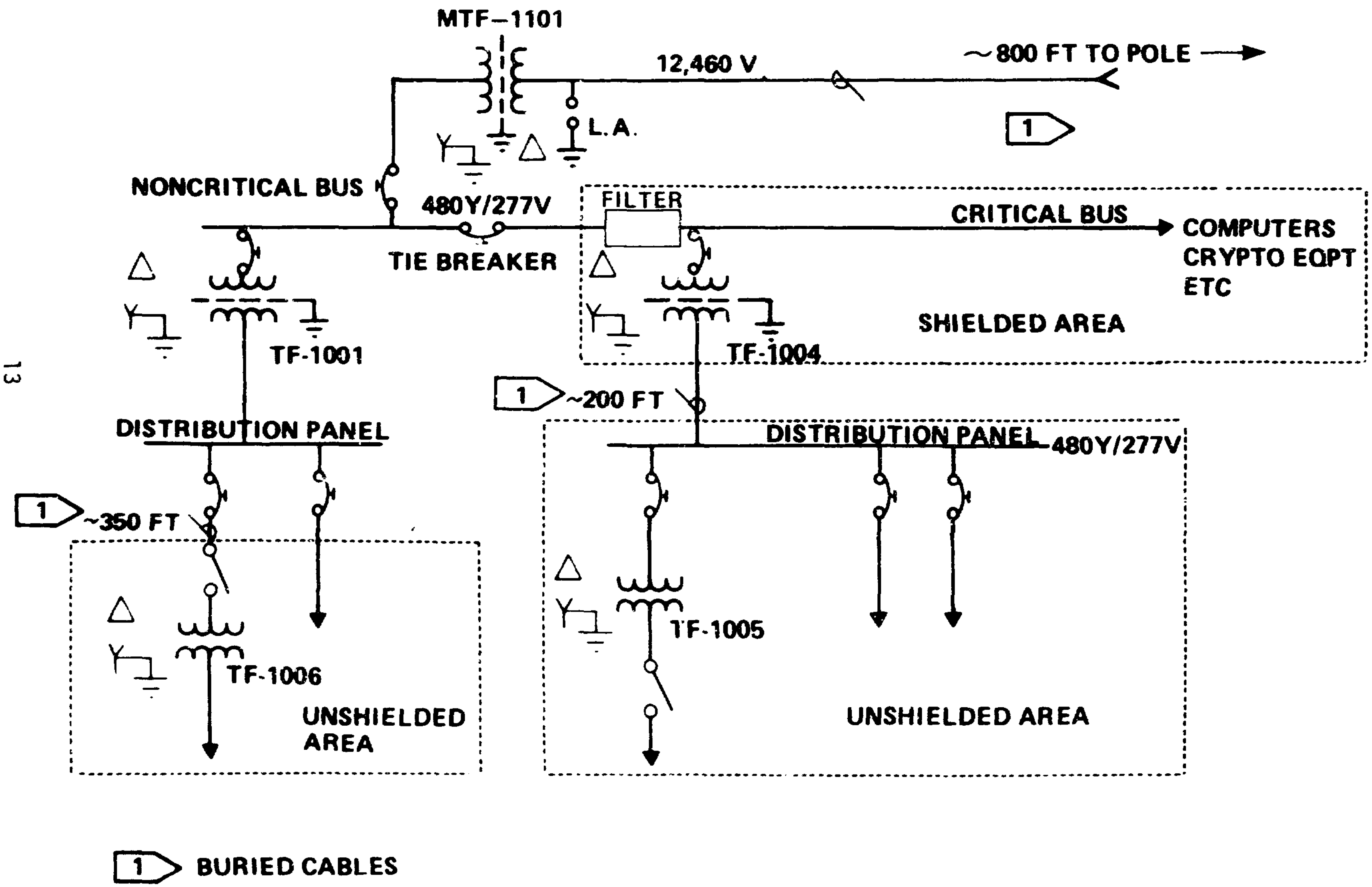
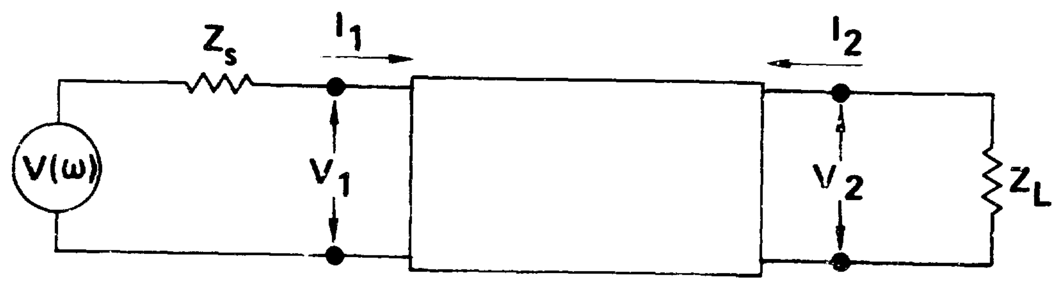


FIGURE 1 EXAMPLE POWER SYSTEM



$$I_1 = y_{11}V_1 + y_{12}V_2$$
$$I_2 = y_{21}V_1 + y_{22}V_2$$

$$y_{11} = \frac{I_1}{V_1} \quad \text{FOR } V_2 = 0$$

ETC.

$$V_1 = A\,V_2 + B\,I_2$$
$$I_1 = C\,V_2 + D\,I_2$$

$$A = \frac{V_1}{V_2} \quad \text{FOR } V_2 = 0$$

ETC

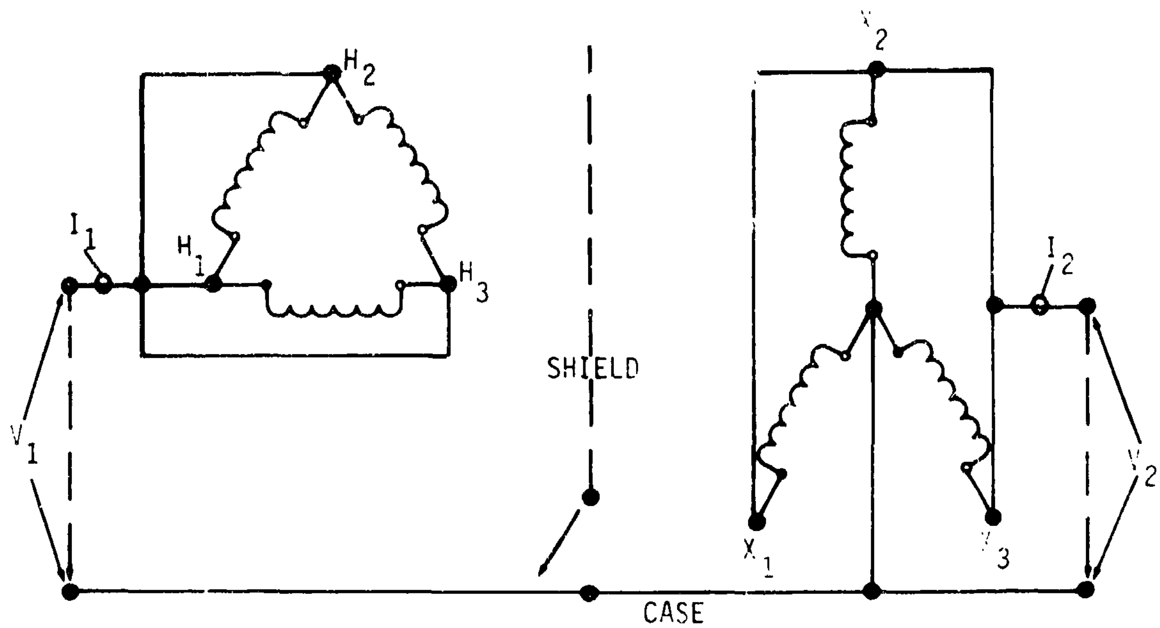
UNLOADED VOLTAGE TRANSFER RATIO (FREQUENCY DOMAIN):

$$\frac{V_2}{V_1} = \frac{y_{12}}{y_{22}} = \frac{1}{A}$$

SHORTED CURRENT TRANSFER RATIO (FREQUENCY DOMAIN):

$$\frac{I_2}{I_1} = \frac{y_{12}}{y_{11}} = \frac{1}{D}$$

FIGURE 2 TWO-PORT PARAMETERS



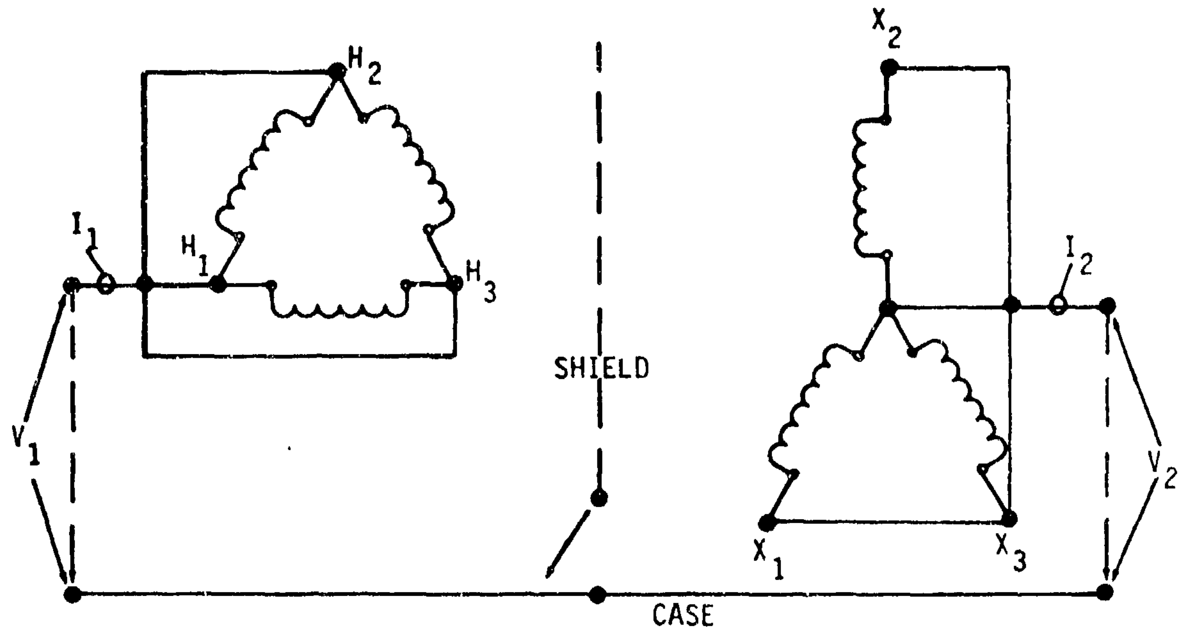
MEASUREMENT TECHNIQUE:

(1) SET $V_2 = 0$(SHORT)
DRIVE V_1
MEASURE $Y_{11} = \frac{I_1}{V_1}, Y_{21} = \frac{I_2}{V_1}$

(2) SET $V_1 = 0$
DRIVE V_2
MEASURE $Y_{22} = \frac{I_2}{V_2}$

(3) REPEAT WITH SHIELD DISCONNECTED

FIGURE 3 MODEL 1



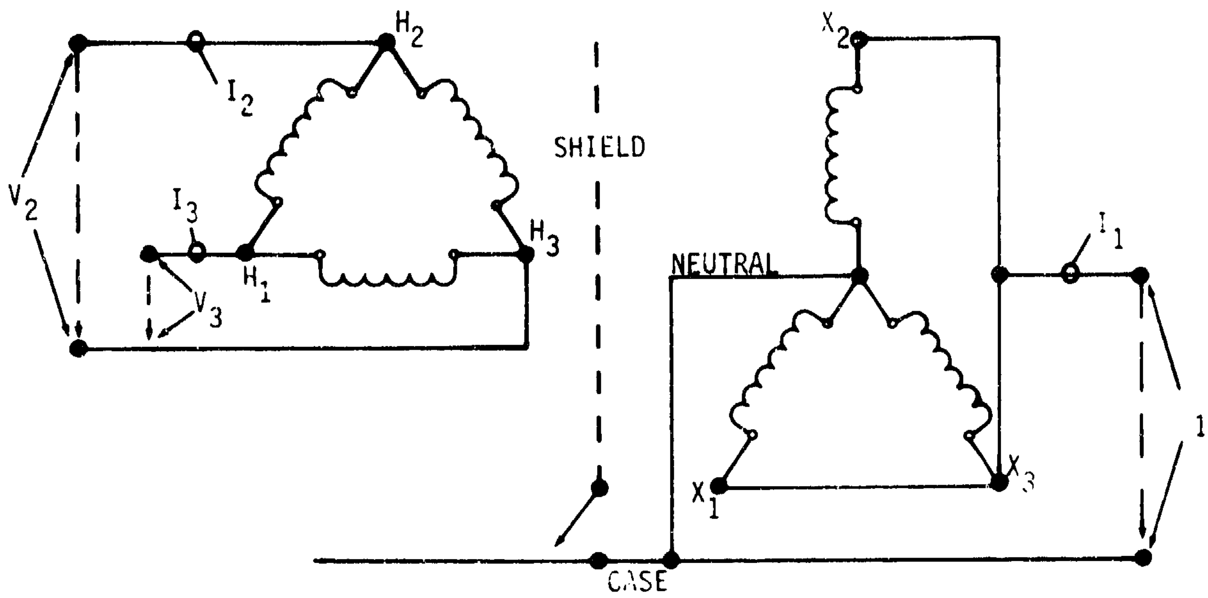
MEASUREMENT TECHNIQUE:

(1) SET $V_2 = 0$(SHORT)
DRIVE V_1
MEASURE $Y_{11} = \frac{I_1}{V_1}, Y_{21} = \frac{I_2}{V_1}$

(2) SET $V_1 = 0$
DRIVE V_2
MEASURE $Y_{22} = \frac{I_2}{V_2}$

(3) REPEAT WITH SHIELD DISCONNECTED

FIGURE 4 MODE 2



MEASUREMENT TECHNIQUE:

(1) SET V_2, V_3 = 0 (SHORT)
DRIVE V_1
MEASURE $Y_{11} = \frac{I_1}{V_1}$, $Y_{21} = \frac{I_2}{V_1}$, $Y_{31} = \frac{I_3}{V_1}$

(2) SET V_1 = 0 (SHORT)
DRIVE V_2
MEASURE $Y_{22} = \frac{I_2}{V_2}$, $Y_{32} = \frac{I_3}{V_2}$

(3) SET V_1, V_2 =0(SHORT)
DRIVE V_3
MEASURE $Y_{33} = \frac{I_3}{V_3}$

(4) REPEAT WITH SHIELD DISCONNECTED

FIGURE 5 MODE 3

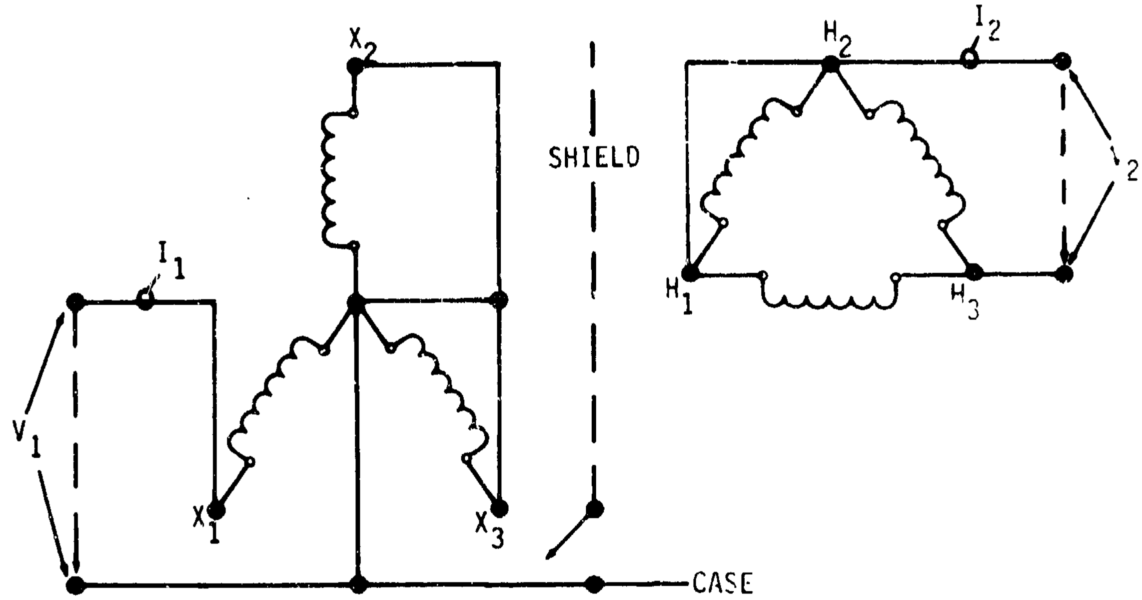
2.1 (Continued)

has been configured to determine the conversion of a common-mode signal on the secondary (y) to a differential-mode signal on the primary (Δ), or vice-versa. Mode 4 was a configuration developed to determine the conversion of a common-mode signal on the primary (Δ) to a differential-mode signal on the secondary (y). The analysis of the mode 4 data was considered of low priority and was not completed. Figure 6 shows the mode 5 configuration. Mode 5 represents the propagation of a differential-mode (between wires) input signal to a differential-mode output signal. Figure 7 shows the configurations used to test the unshielded, single-phase control transformer. Mode 1A is a common-mode primary, differential-mode secondary configuration. Mode 2A is a differential-mode primary, differential mode secondary configuration. **Mode 1A and 2A were used to test the control transformer.**
Figure 8 shows the configuration used to test the unshielded, single-phase 50-kVA power transformer T17363. Mode 3A is a common-mode primary, common-mode secondary configuration.

Figure 9 shows the configuration used to test the three-phase, 50-kVA, 480/277-volt inductrol regulator. Mode 4A is essentially a differential-mode in, differential-mode out configuration for one phase of the regulator. This configuration was chosen as most reasonable to determine the regulator line-to-ground EMP-output level from a common-mode regulator input pulse propagated through a common-mode transformer configuration.

2.2 CALCULATION TECHNIQUE

The majority of the measurements are made in the frequency domain. The transformer-pulse responses are calculated using Fourier-transform techniques. The use of the combination of y-parameter measurements



MEASUREMENT TECHNIQUE:

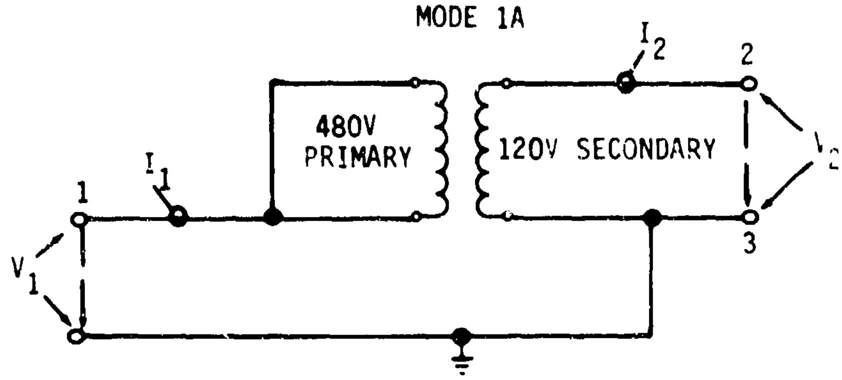
(1) SET $V_2 = 0$ (SHORT)
DRIVE V_1
MEASURE $Y_{11} = \frac{I_1}{V_1}$, $Y_{21} = \frac{I_2}{V_1}$
(SELECT Δ WINDING FOR MAX I_2)

(2) SET $V_1 = 0$ (SHORT)
DRIVE V_2
MEASURE $Y_{22} = \frac{I_2}{V_2}$

(3) REPEAT WITH SHIELD DISCONNECTED

FIGURE 6 MODE 5

MODE 1A

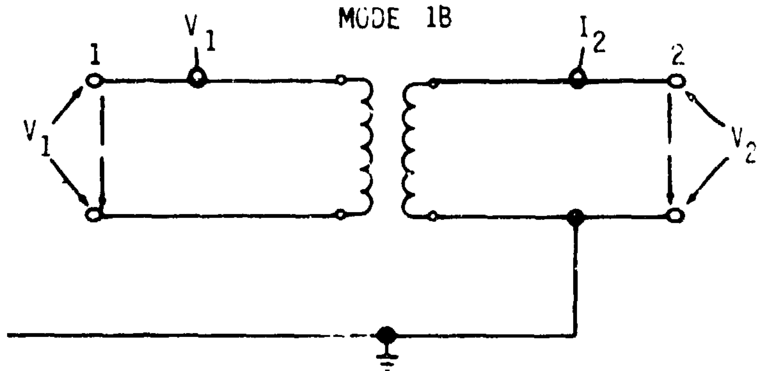


MEASUREMENT TECHNIQUE:

(1) SET V_2, V_3 = 0 (SHORT)
DRIVE V_1

(2) SET V_1 = 0 (SHORT)
DRIVE V_2

MODE 1B

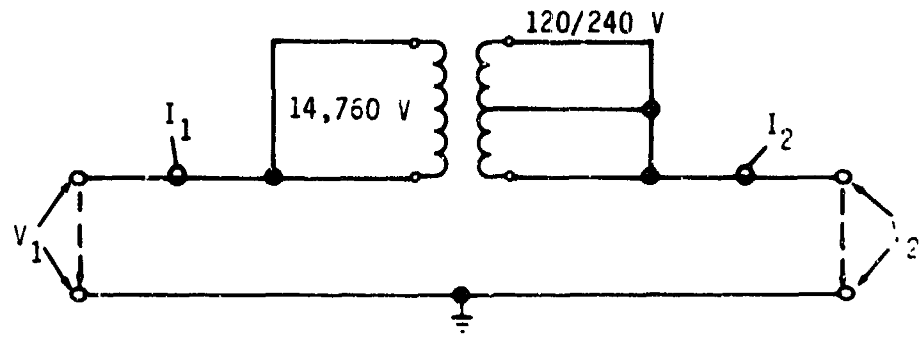


MEASUREMENT TECHNIQUE:

(1) SET V_2 = 0 (SHORT)
DRIVE V_1
MEASURE $Y_{11} = \frac{I_1}{V_1}$, $Y_{21} = \frac{I_2}{V_1}$

(2) SET V_1 =0 (SHORT)
DRIVE V_2
MEASURE $Y_{22} = \frac{I_2}{V_2}$

FIGURE 7 MODE 1A & 2A



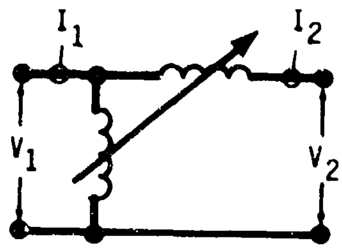
TRANSFORMER T 17363

MEASUREMENT TECHNIQUE:

(1) SET $V_2 = 0$ (SHORT)
DRIVE V_1
MEASURE $Y_{11} = \frac{I_1}{V_1}$, $Y_{21} = \frac{I_2}{V_1}$

(2) SET $V_1 = 0$ (SHORT)
DRIVE V_2
MEASURE $Y_{22} = \frac{I_2}{V_2}$

FIGURE 8 MODE 3A



SINGLE PHASE REGULATOR

MEASUREMENT TECHNIQUE

1) Set for maximum boost

a) Set V_2=0 (short)

Drive V_1

Measure $Y_{11} = \frac{I_1}{V_1}$, $Y_{21} = \frac{I_2}{V_1}$

b) Set V_1=0 (short)

Drive V_2

Measure $Y_{22} = \frac{I_2}{V_2}$

2) Repeat for maximum buck

Figure 9 Mode 4A, Inductrol Regulator

2.2 (Continued)

in the frequency domain with calculation of the time-domain pulse responses allows excellent flexibility in the choice of pulse shape, load impedance, and source impedance. The pulse-time constants are chosen to obtain the desired frequency content. Figure 10 shows the spectrum of a double-exponential pulse. The bulk of the energy in the pulse is between the low-frequency break point f_α and the high-frequency break point f_β, consequently matching of f_α and f_β to the desired frequency range has been the key to selection of appropriate pulse shapes. Table 5 shows the pulse parameters which have been used in the transformer calculations. P_1 represents the approximate frequency content of pulses resulting from EMP fields coupling into inductances. The data supported the use of P_1 only for T17363. P2 represents typical pulsers coupled to a transformer, P_3 is an approximation to a step function and did not compute properly. P_4 was chosen to fit the majority of the swept-cw data. P_5 is typical of free-field environments, cable pickup, etc. P_4 and P_5 were used for the majority of the calculations. The t_p column of **table 5 gives the time** to the peak for the corresponding pulse, where $t_p = \frac{1}{\beta-\alpha} \ln\left(\frac{\beta}{\alpha}\right)$

Figure 11 shows the pulse-frequency ranges for P_1, P_4, and P_5 compared with the frequency ranges for the data. Most of the network-analyzer data was taken from 30 kH_z to 32 MH_z, except for T17363, for which the upper frequency limit was 100 MH_z.

To summarize the overall calculational approach, the data consists of y parameters which **are** digitized and converted to ABCD parameters, then the pulse response is calculated using input information on either card or tape. This summary is shown in figure 12. A more detailed data flow is shown in figures 13, 14, and 15, which are self explanatory.

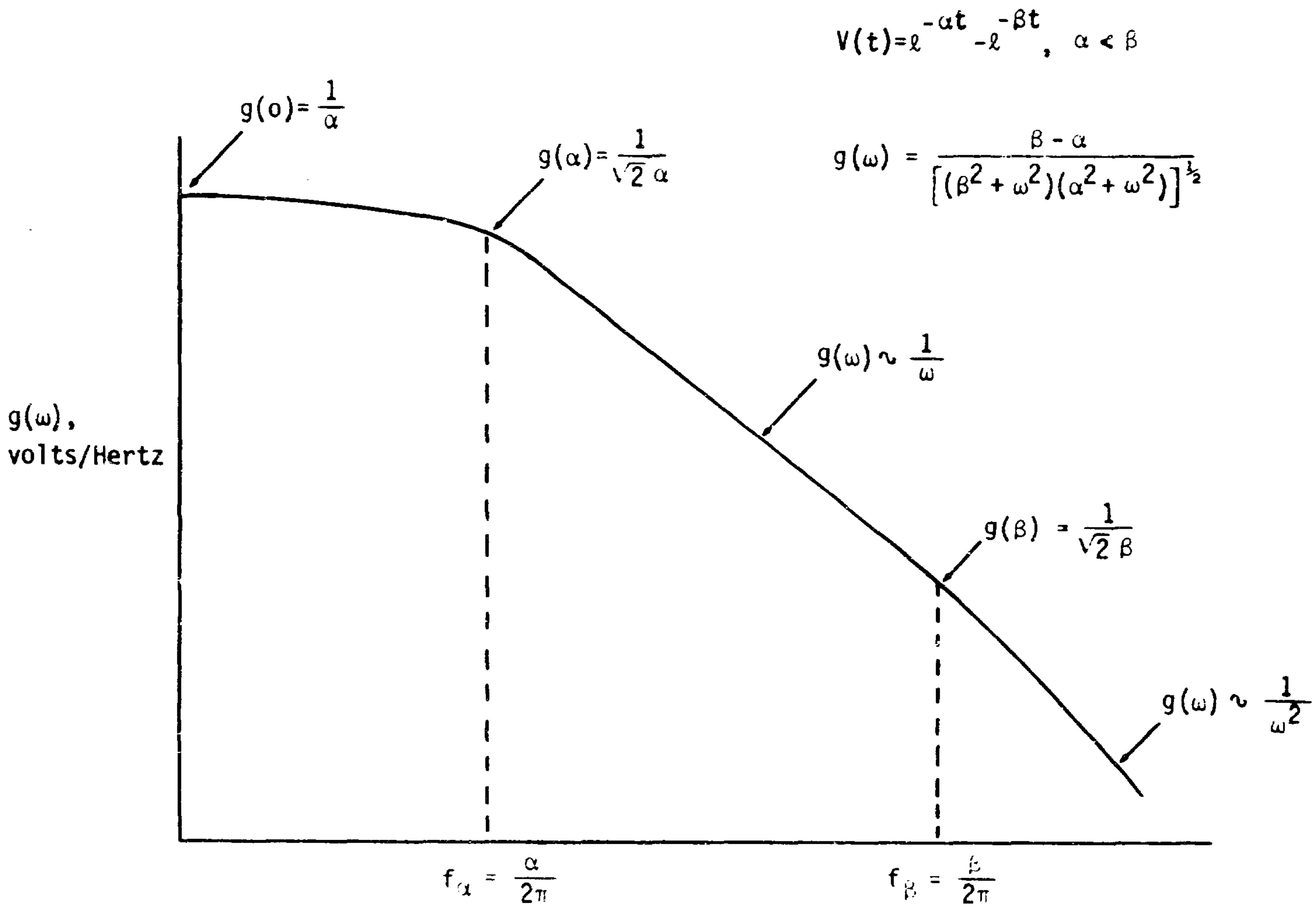


FIGURE 10 GENERAL SPECTRUM OF DOUBLE EXPONENTIAL PULSE

TABLE 5 PULSE PARAMETERS

	$\alpha(\mathrm{Sec}^{-1})$	$\beta(\mathrm{Sec}^{-1})$	f_α (Hertz)	f_β (Hertz)	T_p (Sec)
P_1	6×10^7	5×10^8	10^7	8×10^7	4.8×10^{-9}
P_2	2×10^6	3×10^7	3×10^5	5×10^6	9.8×10^{-8}
P_3	0.1	10^{10}	1.6×10^{-2}	1.6×10^9	2.5×10^{-9}
P_4	4×10^5	10^8	6.4×10^4	1.6×10^7	5.5×10^{-8}
P_5	4×10^6	5×10^8	6.4×10^5	8×10^7	9.8×10^{-9}

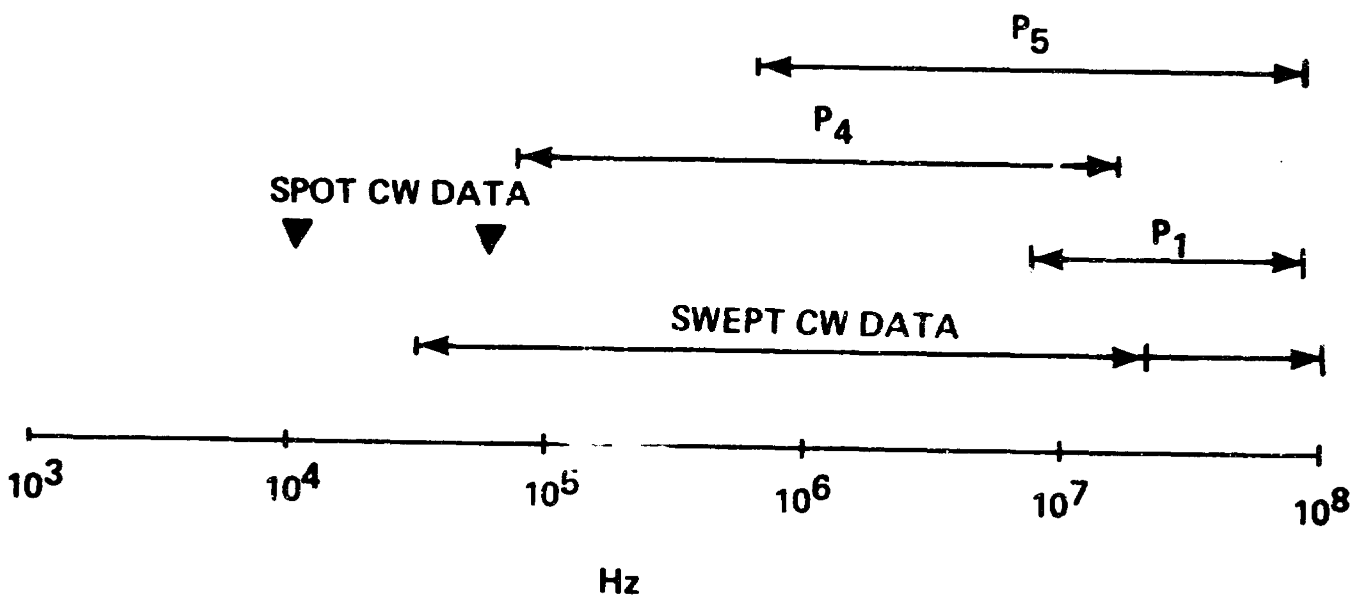


FIGURE 11 PULSE FREQUENCY RANGES

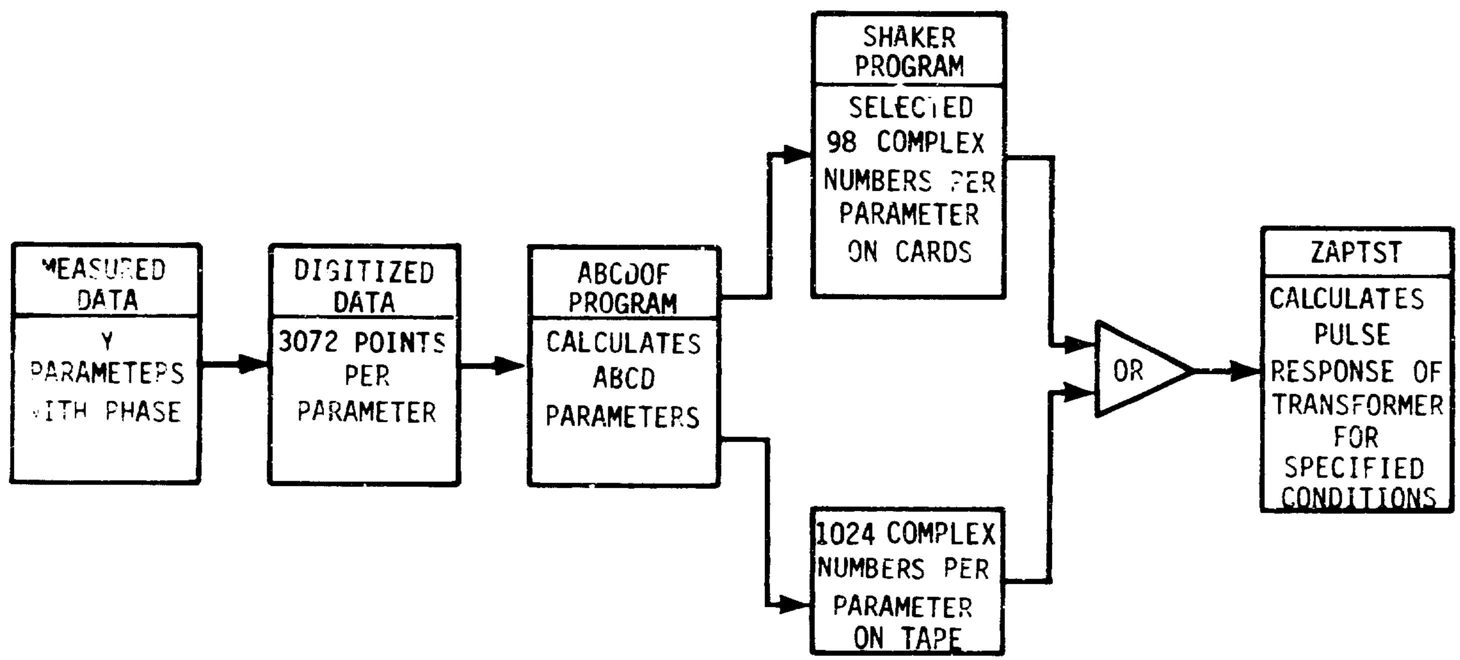


FIGURE 12 DATA FLOW SUMMARY

74E70-14

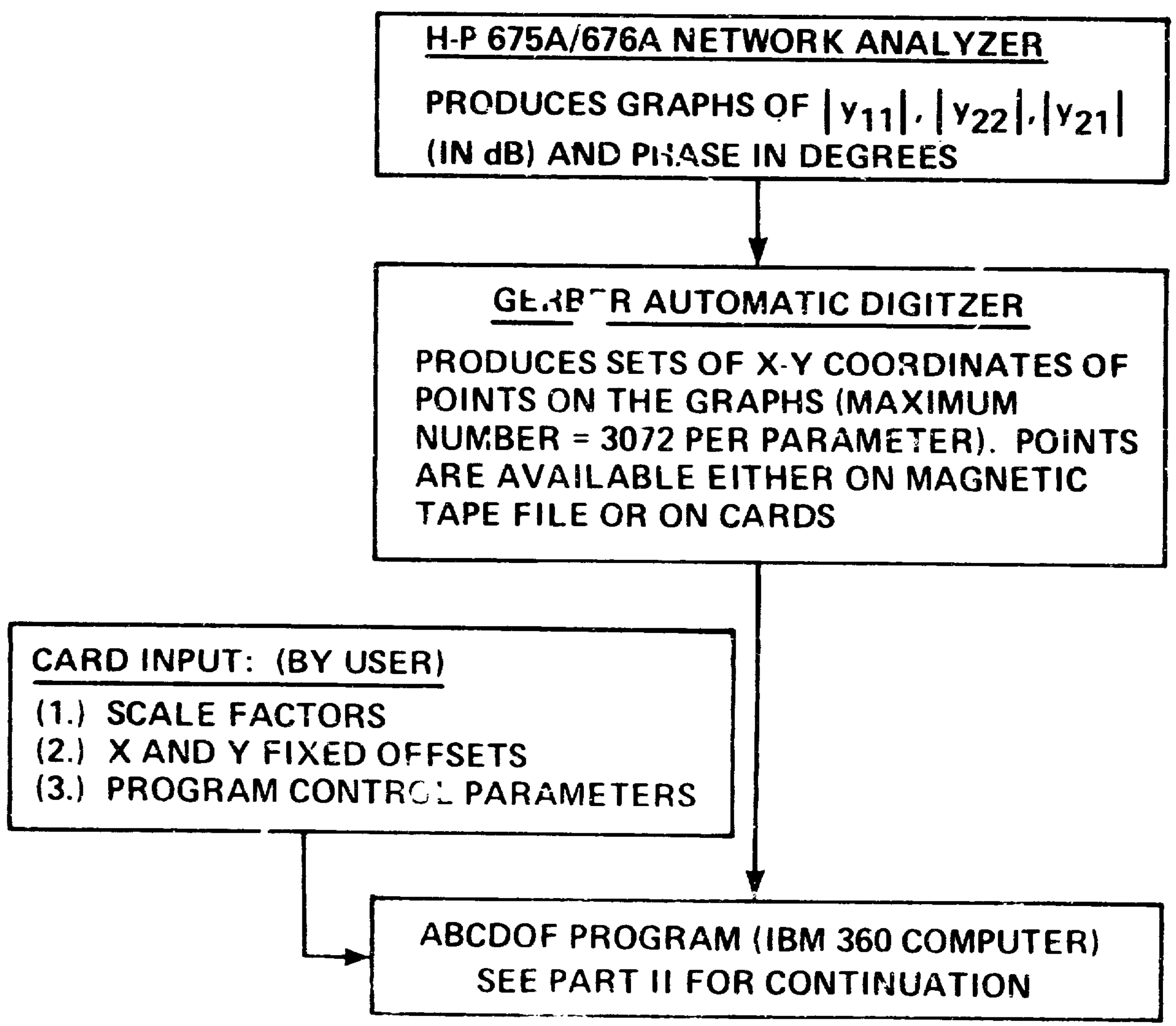


FIGURE 13 DATA FLOW DIAGRAM PART I

74E70-1?

ABCDOF PROGRAM

(1.) TAKES VARIABLE NUMBER OF NON-UNIFORMLY SPACED MAGNITUDE AND PHASE DATA POINTS, APPLIES SCALE FACTORS, OFFSETS, AND CORRECTIONS

(2.) USING TABLE LOOK-UP AND INTERPOLATION, PRODUCES 1024 UNIFORMLY SPACED (IN FREQUENCY) COMPLEX VALUES OF Y_{11}, Y_{22}, AND Y_{21}

(3.) FROM (2.) COMPUTES 1024 UNIFORMLY SPACED COMPLEX VALUES EACH FOR A, B, C, D, DET. (ABCD), OPEN CIRCUIT VOLTAGE RATIO, AND SHORT CIRCUIT CURRENT RATIO. ALL OF THESE SUPPLIED IN GRAPHICAL FORM AS MAGNITUDE (IN dB), PHASE, REAL PART, IMAGINARY PART VS FREQUENCY

(4a.) FORTRAN DATA STATEMENT OPTION

- REDUCES THE 1024 POINT SETS TO 98 POINTS CHOSEN FOR OPTIMUM RECONSTRUCTION OF THE FUNCTION USING TABLE LOOK-UP AND POLYNOMIAL INTERPOLATION ROUTINE
- OUTPUTS REDUCED DATA SET ON CARDS, FORMATTED AS FORTRAN DATA STATEMENT CARDS FOR INCLUSION IN MODEL SUBROUTINES

→ TO ZAPTST (SHAKER DATA)

(4b.) TAPE-FILE DATA TRANSFER OPTION

- WRITES THE FULL 1024 POINT SETS WITH APPROPRIATE IDENTIFYING INFORMATION ON MAGNETIC TAPE FOR LATER USE BY OTHER PROGRAMS

→ TO ZAPTST (TAPE DATA)

FIGURE 14 DATA FLOW DIAGRAM – PART II

74E 70 15

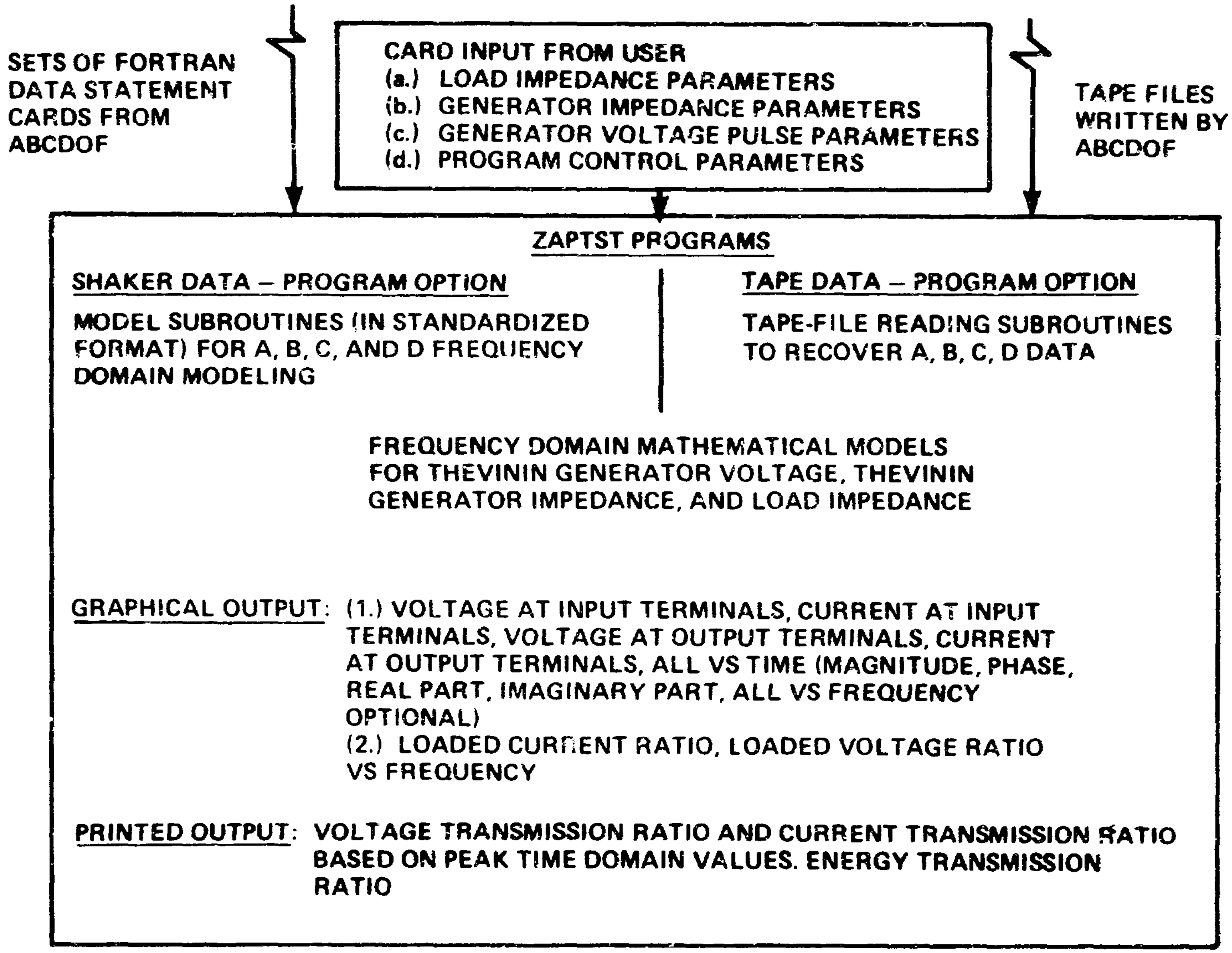
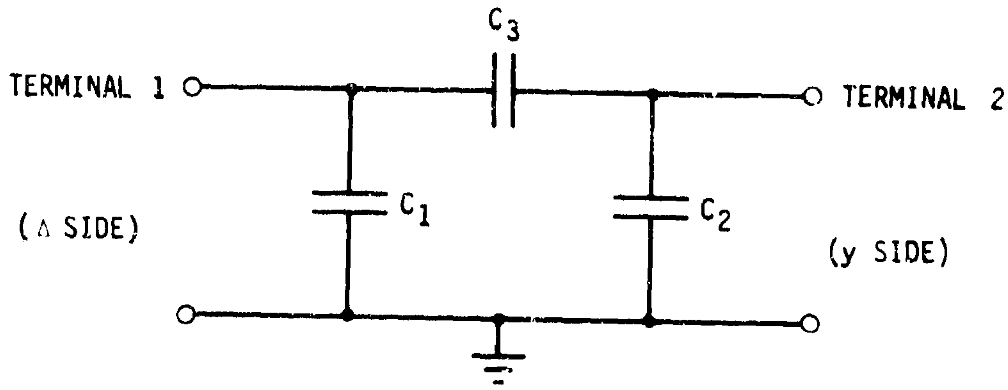


FIGURE 15 DATA FLOW DIAGRAM – PART III

2.3 CAPACITIVE PI NETWORK

The low-frequency capacitance measurements of transformer TF1004 were used in a pi-network simulation of that transformer. The network used is shown in figure 16. The corresponding y and ABCD parameters were calculated and input to ZAPTST. The resulting isolation calculations are quite similar to the TF1004 results, although some y-parameter values were significantly different.



$C_1 = 3.6 \times 10^{-9}F$

$C_2 = 5 \times 10^{-9}F$

$C_3 = 0.5 \times 10^{-9}F$

Figure 16 PI 1004

3.0 DETAILED RESULTS

Values of transformer source and load resistance were chosen to permit determination of the pulse transfer over the range of resistances typical of the application of each transformer. Table 5a provides a summary of the calculations, and provides a concise guide to the location of particular data. Data tables, tables 6 through 38, are provided to show the results of the isolation calculations performed. Pulses P4 and P5, and for one transformer, pulse P1, were used. The peak pulse voltage transfer ratios V_T, peak pulse current transfer ratios I_T, and integrated energy transfer ratios E_T, were calculated. The ratios were expressed in dB. Plots were made of selected data to show transformer isolation as a function of both source resistance Z_S, and load resistance Z_L (figures 17 through 111). Table 5a indicated the particular data that were plotted. Each plot of isolation versus source resistance Z_S is labled with its associated value of load resistance. Each plot of isolation versus load resistance Z_L is labled with its associated value of source resistance.

TABLE 5a CALCULATIONS SUMMARY

TRANSFORMER	MODE, SHIELD	PULSE DIRECTION		TABLE NO.	FIGURE NUMBER				
		IN	OUT		Z_L P1	Z_S P4	Z_L P4	Z_S P5	Z_L P5
TF12	1 ON	Y	Δ	6		—	17	19	21
		Δ	Y	7		—	18	20	22
	1 OFF	Y	Δ	8		—	23	25	27
		Δ	Y	9			24	26	28
TFAA/FA	1 ON	Y	Δ	10	—		29	31	33
		Δ	Y	11			30	32	34
	1 OFF	Y	Δ	12			35	37	38
		Δ	Y	13		—	36	—	39
	2 ON	Y	Δ	14	—	—	40		42
		Δ	Y	15		—	41		43
	2 OFF	Y	Δ	16		—	44	46	47
		Δ	Y	17	—	—	45		48
	3 ON	Y	Δ	18			49	51	53
		Δ	Y	19		—	50	52	54
TF1004	1 ON	Y	Δ	20	—		55	57	59
		Δ	Y	21			56	58	60
	2 ON	Y	Δ	22		—	61	63	65
		Δ	Y	23			62	64	66
π 1004	2 ON	Δ	Y	24			67	68	69
TF1010	1 ON	Y	Δ	25			70	72	74
		Δ	Y	26		—	71	73	75
	2 ON	Y	Δ	27			76		78
		Δ	Y	28	—		77	—	79
	5 ON	Y	Δ	29			80	—	82
		Δ	Y	30	—		81		83
CONTROL	1A	HV	LV	31	—		84		86
	2A	HV	LV	32	—		85		87
T17363	3A	LV	HV	33	88	—	90	92	94
		HV	LV	34	89	—	91	93	95
REGULATOR	4A-	1	2	35		96	98	100	102
	BOOST	2	1	36		97	99	101	103
	4A-	1	2	37		104	106	108	110
	BUCK	2	1	38		105	107	109	111

TABLE 6 TRANSFORMER TF12

MODE: 1 SHIELD: ON
INPUT: COM. Y OUTPUT: COM.
COMPUTER RUN: F0003399 DATA: TAPE
*ARED5068 * INVERSE SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-5.10	-130.87	-67.23	P4
2A	1	.001	-89.57	-15.36	-54.30	
3A	2	10	-14.88	-13.43	-17.18	
4A	15	10	-19.41	-18.43	-17.31	
5A	2	32	-10.03	-23.65	-17.52	
6A	15	32	-14.54	-23.54	-17.40	
7A	2	40	-9.38	-24.93	-17.75	
8A	15	40	-13.89	-24.81	-17.58	
1B	1	10^7	-7.57	-128.44	-61.39	P5
2B	1	.001	-91.56	-12.50	-43.95	
3B	2	10	-16.55	-16.86	-8.88	
4B	15	10	-20.18	-17.89	-9.82	
5B	2	32	-11.83	-22.26	-9.61	
6B	15	32	-15.42	-23.24	-10.42	
7B	2	40	-11.23	-23.60	-10.04	
8B	15	40	-14.80	-24.57	-10.83	
9B*	10	2.5	-27.30	-14.91	-12.09	
10B*	10	5	-22.48	-15.98	-10.34	
11B*	10	10	-18.78	-17.38	-6.92	
12B*	10	15	-16.62	-18.67	-7.16	
13B*	10	20	-15.54	-19.92	-8.42	
14B*	10	32	-14.04	-22.34	-9.45	
15B*	10	50	-13.01	-25.03	-10.44	
16B*	10	.001	-93.86	-13.61	-44.53	
17B*	15	10	-19.03	-18.00	-9.86	

TABLE 7 TRANSFORMER TF12

MODE: 1
SHIELD: ON
INPUT: COM. X
OUTPUT: COM.Y
COMPUTER RUN: FBLU3007, F0001819 *ARED5075
DATA: * INVERSE SHAKER TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-13.32	-128.83	-63.74	P4
2A	1	.001	-89.94	-5.42	-41.02	
3A	10	2	-28.71	-7.80	-10.75	
4A	10	15	-19.20	-15.73	-9.32	
5A	32	2	-32.71	-7.99	-11.10	
6A	32	15	-22.93	-15.81	-9.57	
7A	40	2	-33.57	-7.98	-11.02	
8A	40	15	-23.79	-15.78	-9.49	
1B	1	10^7	-14.77	-128.36	-64.21	P5
2B	1	.001	-91.36	-4.92	-40.86	
3B	10	2	-29.24	-7.48	-10.64	
4B	10	15	-19.68	-15.45	-9.49	
5B	32	2	-30.81	-8.14	-11.17	
6B	32	15	-21.20	-16.06	-9.95	
7B	40	2	-30.98	-8.21	-11.25	
8B	40	15	-21.35	-16.12	-10.03	
9B*	10	10	-20.52	-12.97	-9.20	
10B*	10	32	-17.81	-19.96	-11.42	
11B*	10	40	-17.52	-21.61	-12.07	
12B*	10	.001	-92.61	-5.70	-41.78	
13B*	10	15	-19.35	-14.96	-9.77	

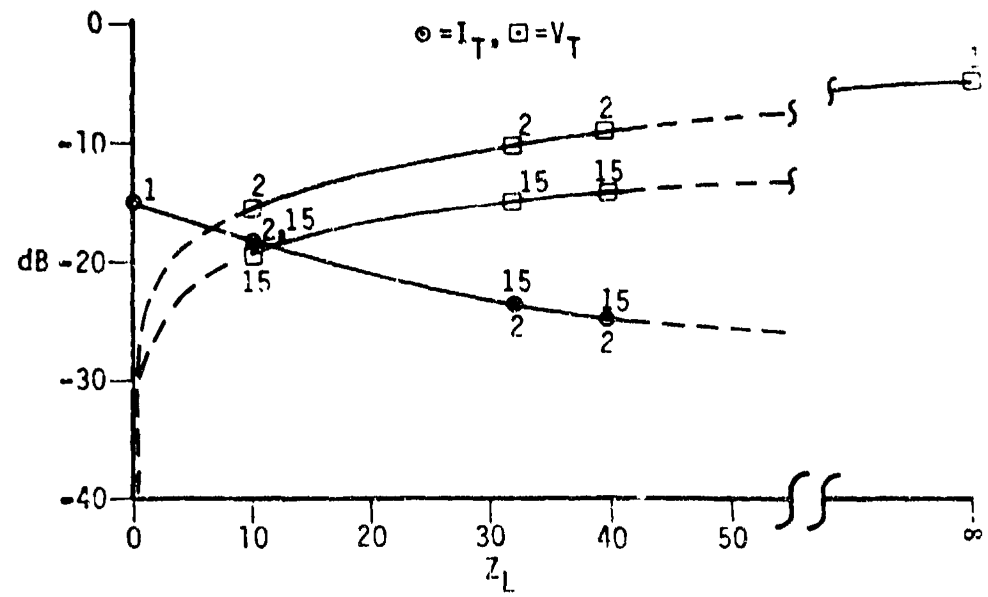


FIGURE 17 MODE 1 INPUT Y TRANS. TF12
SHIELD ON OUTPUT Δ PULSE P4

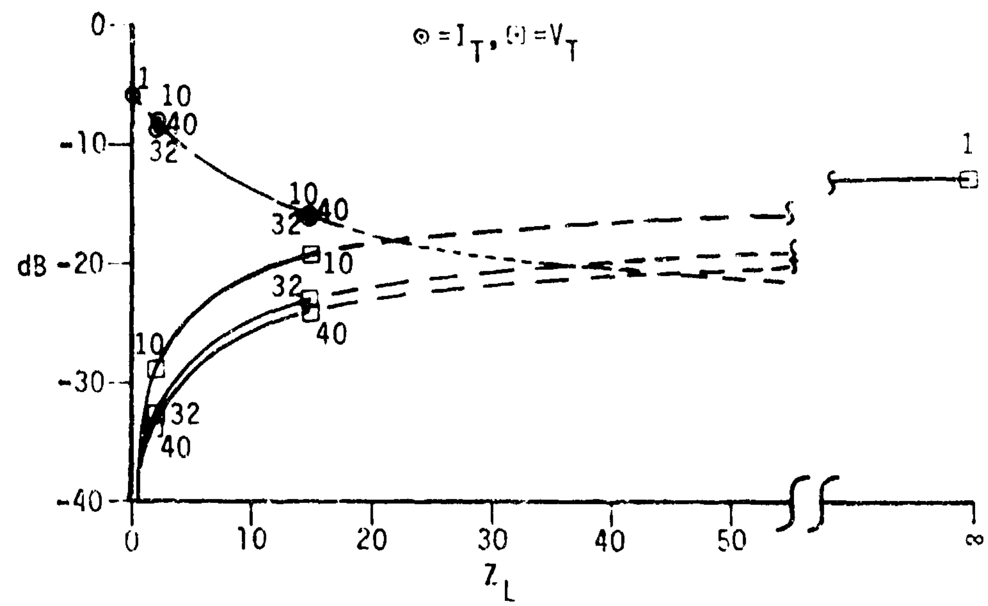


FIGURE 18 MODE 1 INPUT Δ TRANS. TF12
SHIELD ON OUTPUT " PULSE P4

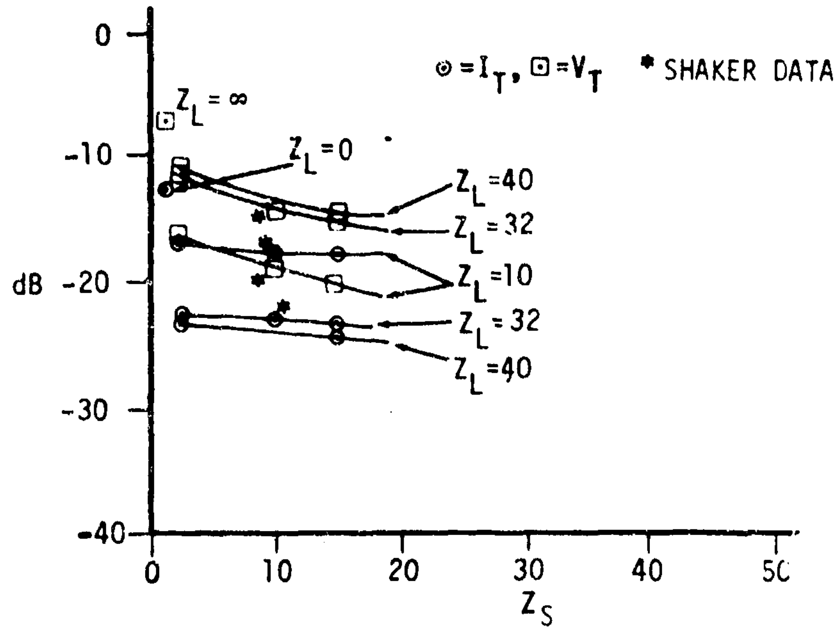


FIGURE 19 MODE 1 INPUT Y TRANS. TF12
SHIELD ON OUTPUT Δ PULSE P5

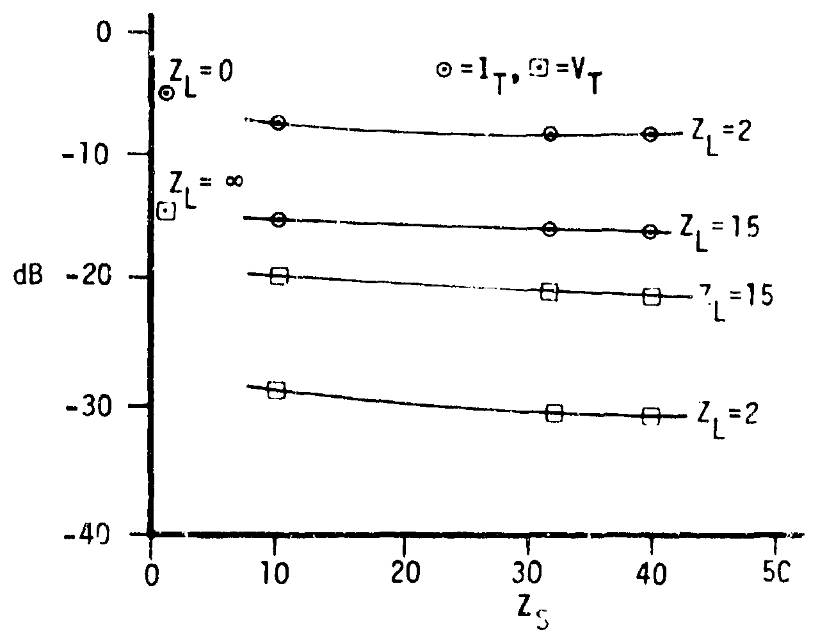


FIGURE 20 MODE 1 INPUT Δ TRANS. TF12
SHIELD ON OUTPUT Y PULSE P5

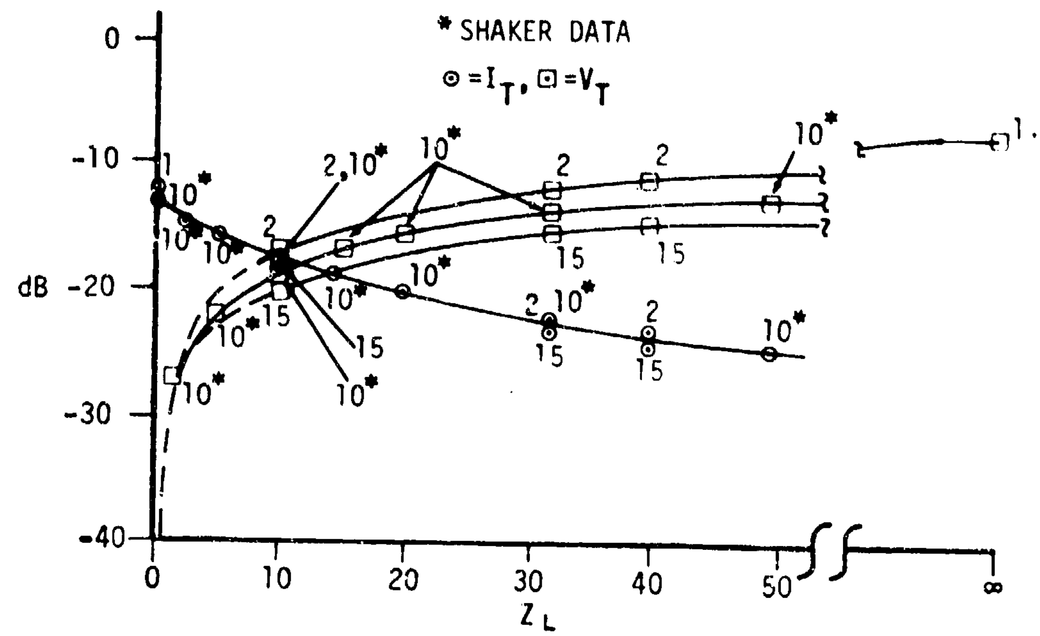


FIGURE 21 MODE 1 INPUT Y TRANS. TF12
SHIELD ON OUTPUT Δ PULSE P5

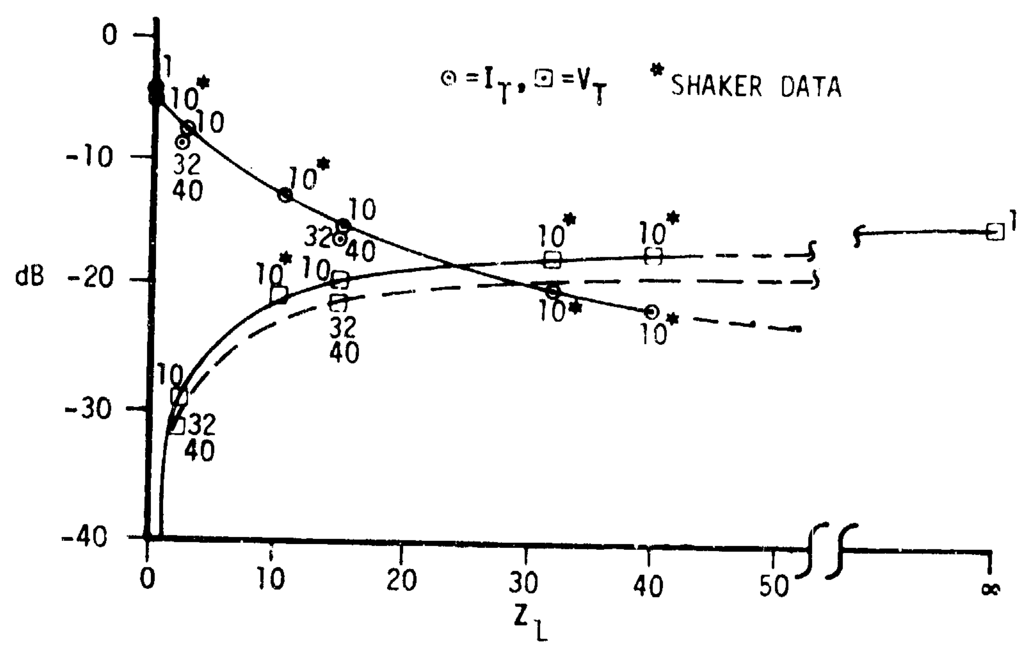


FIGURE 22 MODE 1 INPUT Δ TRANS. TF12
SHIELD ON OUTPUT Y PULSE P5

TABLE 8 TRANSFORMER TF12

MODE: 1	SHIELD: OFF
INPUT: COM. Y	OUTPUT: COM. [illegible]
COMPUTER RUN: A0001654	DATA: INVERSE SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-3.92	-129.62	-65.45	P4
2A	1	.001	-88.78	-14.75	-54.74	
3A	15	10	-17.0	-16.56	-17.32	
4A	2	32	-8.26	-22.32	-16.72	
5A	15	32	-12.35	-21.81	-16.80	
6A						
7A						
8A						
1B	1	10^7	-6.47	-126.84	-59.39	P5
2B	1	.001	-90.94	-11.79	-44.66	
3B	15	10	-16.64	16.68	-10.42	
4B	2	32	-10.64	20.66	-8.64	
5B	15	32	-13.23	-21.18	-9.[illegible]	
6B						
7B						
8B						

TABLE 9 TRANSFORMER TF12

MODE: 1 SHIELD: OFF
INPUT: COM. Δ OUTPUT: COM. Y
COMPUTER RUN: ARED2081 DATA: INVERSE SHAKER
A0001657

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-12.79	-127.98	-60.99	P4
2A	1	.001	-88.98	-5.99	-39.47	
3A	10	15	-17.69	-15.51	-8.33	
4A	32	2	-31.38	-7.50	-10.25	
5A	32	15	-21.15	-15.09	-7.68	
6A						
7A						
8A						
1B	1	10^7	-14.58	-126.96	-62.22	P5
2B	1	.001	-90.75	-4.74	-39.50	
3B	10	15	-18.65	-15.51	-8.05	
4B	32	2	-26.49	-8.44	-9.48	
5B	32	15	-19.25	-15.68	-6.74	
6B						
7B						
8B						

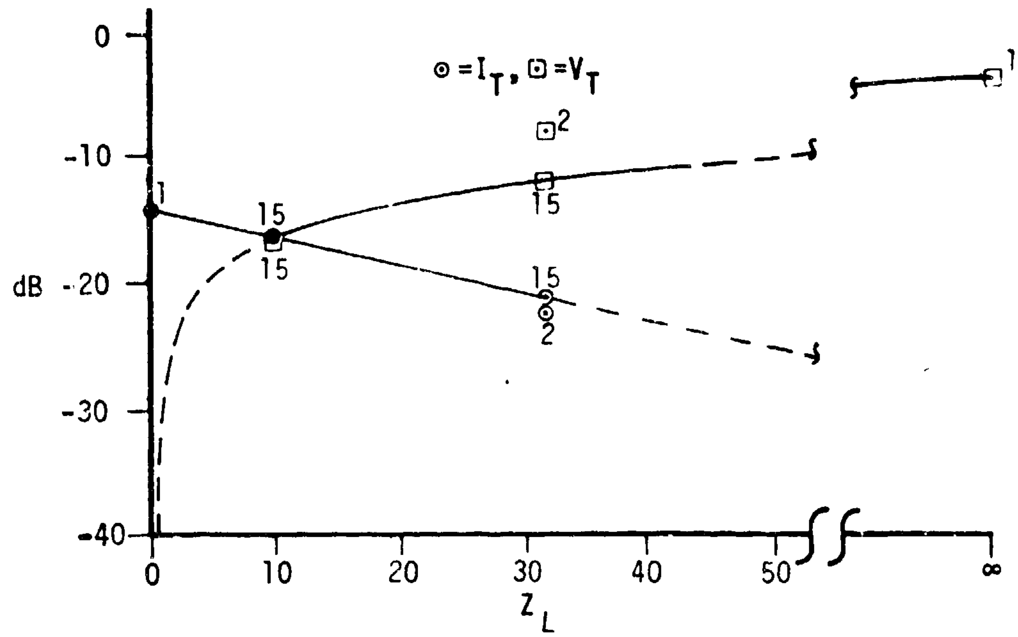


FIGURE 23 MODE 1 INPUT Y TRANS. TF12
SHIELD OFF OUTPUT Δ PULSE P4

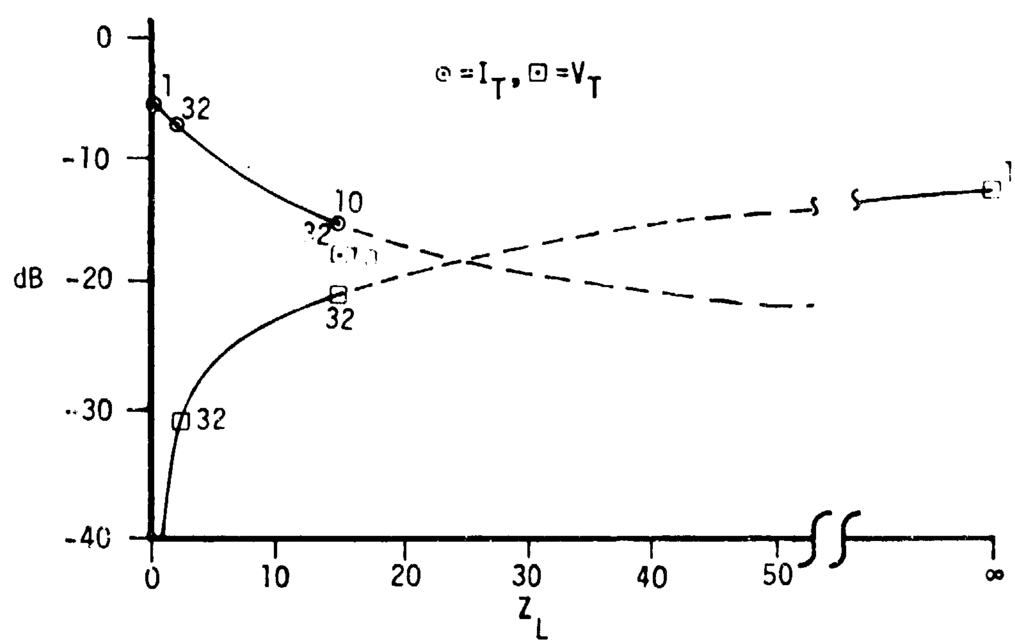


FIGURE 24 MODE 1 INPUT Δ TRANS. TF12
SHIELD OFF OUTPUT Y PULSE P4

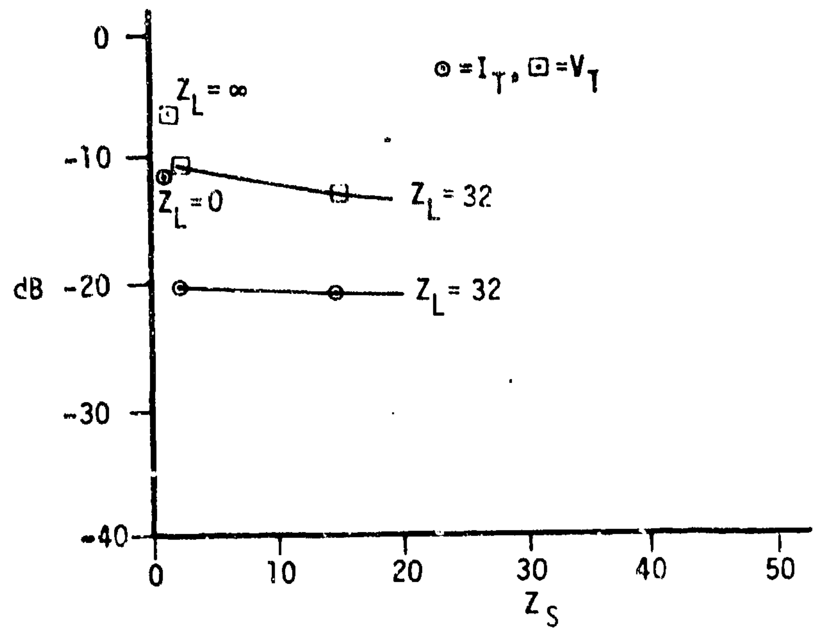


FIGURE 25 MODE 1 INPUT Y TRANS. TF12
SHIELD OFF OUTPUT Δ PULSE P5

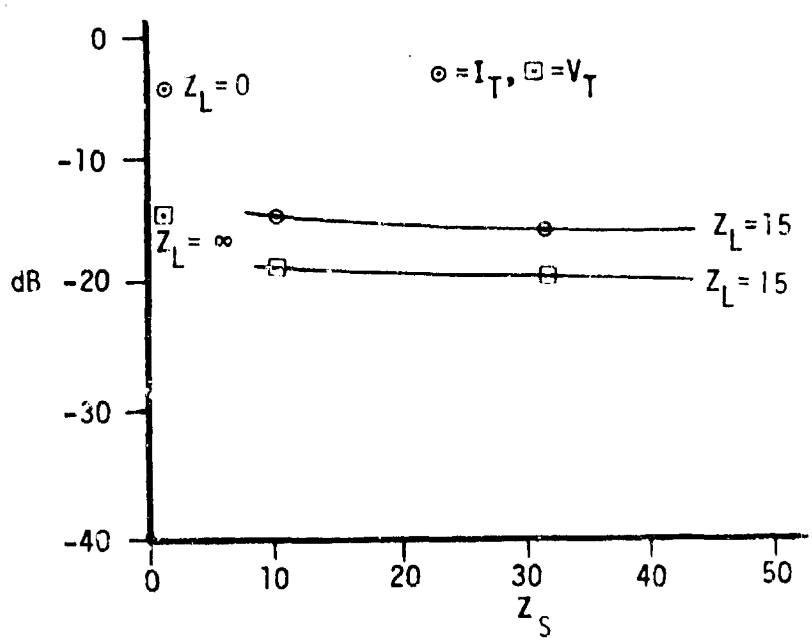


FIGURE 26 MODE 1 INPUT Δ TRANS. TF 12
SHIELD OFF OUTPUT Y PULSE P5

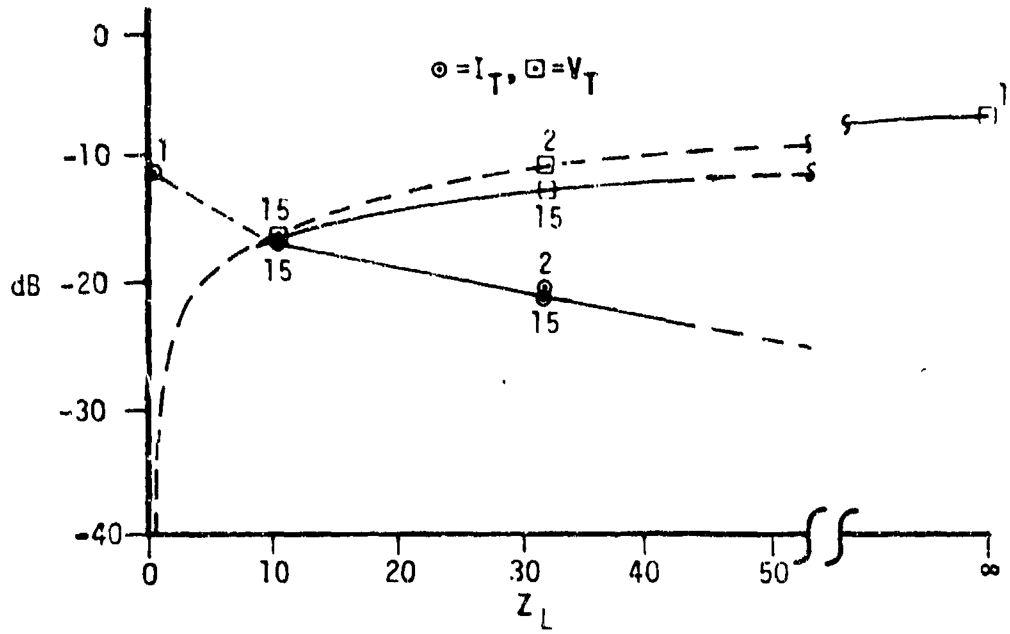


FIGURE 27 MODE 1 INPUT Y TRANS. TF 12
SHIELD OFF OUTPUT Δ PULSE P5

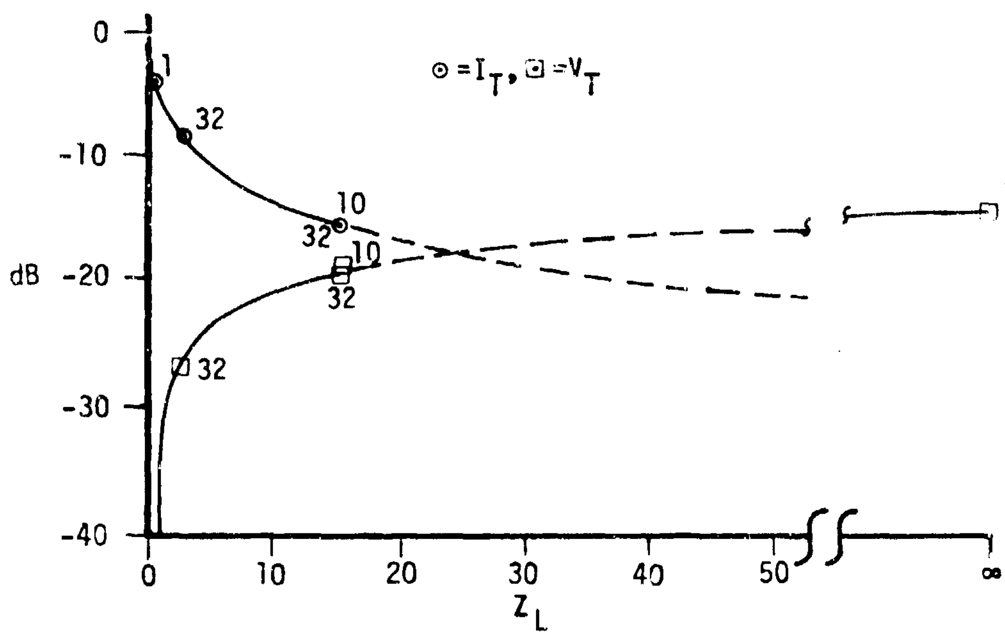


FIGURE 28 MODE 1 INPUT Δ TRANS. TF 12
SHIELD OFF OUTPUT Y PULSE P5

TABLE 10 TRANSFORMER TFAA/FA

MODE: 1
INPUT: COM. Y
COMPUTER RUN: FBLU3008
F0001822

SHIELD: ON
OUTPUT: COM.
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-3.95	-88.47	-64.27	P4
2A	1	.001	-128.01	-11.66	-52.32	
3A	5	20	-13.56	-16.42	-13.27	
4A	20	20	-16.46	-16.14	-14.79	
5A	5	40	-10.98	-19.57	-13.68	
6A	20	40	-13.97	-19.40	-15.78	
7A	20	30	-14.84	-17.88	-15.21	
8A						
1B	1	10^7	-6.07	-89.40	-43.99	P5
2B	1	.001	-123.62	-7.50	-39.65	
3B	5	20	-13.15	-15.64	-4.24	
4B	20	20	-13.10	-15.57	-6.07	
5B	5	40	-11.09	-19.46	-4.16	
6B	20	40	-11.07	-19.57	-7.06	
7B	20	30	-11.99	-18.0	-6.45	
8B						

TABLE 11 TRANSFORMER YFAA/FA

MODE: 1 SHIELD: ON
INPUT: COM. Δ OUTPUT: COM. Y
COMPUTER RUN: FRED3006 F0001823 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-10.04	-123.26	-55.85	P4
2A	1	.001	-89.08	-3.78	-33.89	
3A	20	5	-25.70	-3.93	-3.38	
4A	20	20	-19.12	-14.04	-2.33	
5A	40	5	-28.55	-8.79	-3.96	
6A	40	20	-21.89	-13.92	-4.06	
7A	30	20	-20.68	-13.95	-3.18	
8A						
1B	1	10^7	-10.15	-12[illegible].0	-56.01	P5
2B	1	.001	-89.68	[illegible]	[illegible]	
3B	20	5	-23.04	-8.80	-3.15	
4B	20	20	-16.58	-13.78	-2.23	
5B	40	5	-24.39	-9.39	-[illegible].16	
6B	40	20	-17.36	-14.45	-3.40	
7B	30	20	-17.32	-14.45	-2.76	
8B						

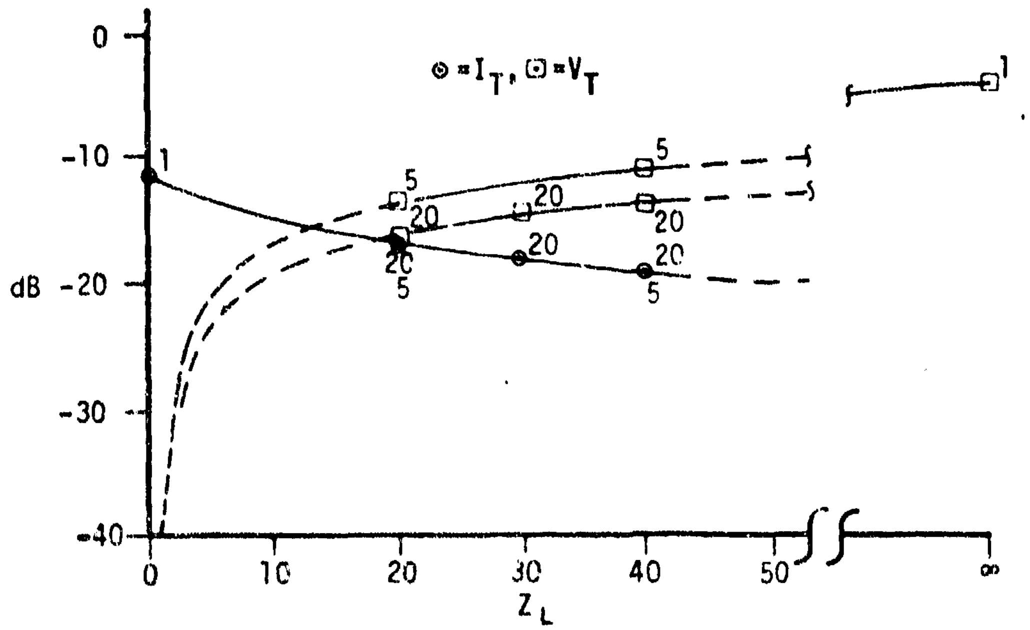


FIGURE 29 MODE 1 INPUT Y TRANS. TFAA/FA
SHIELD ON OUTPUT Δ PULSE P4

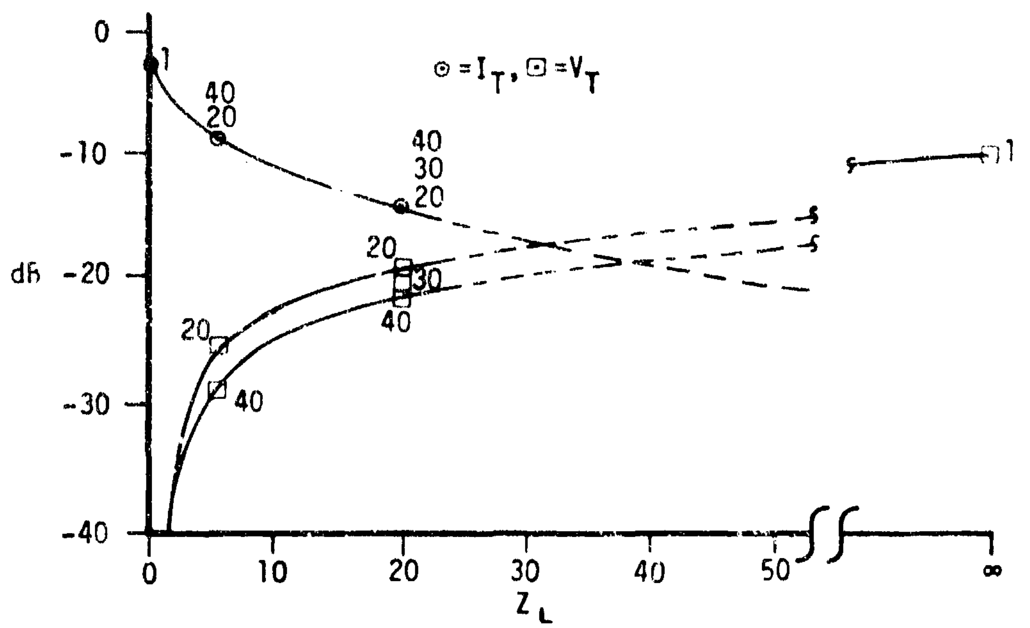


FIGURE 30 MODE 1 INPUT Δ TRANS. TFAA/FA
SHIELD ON OUTPUT Y PULSE P4

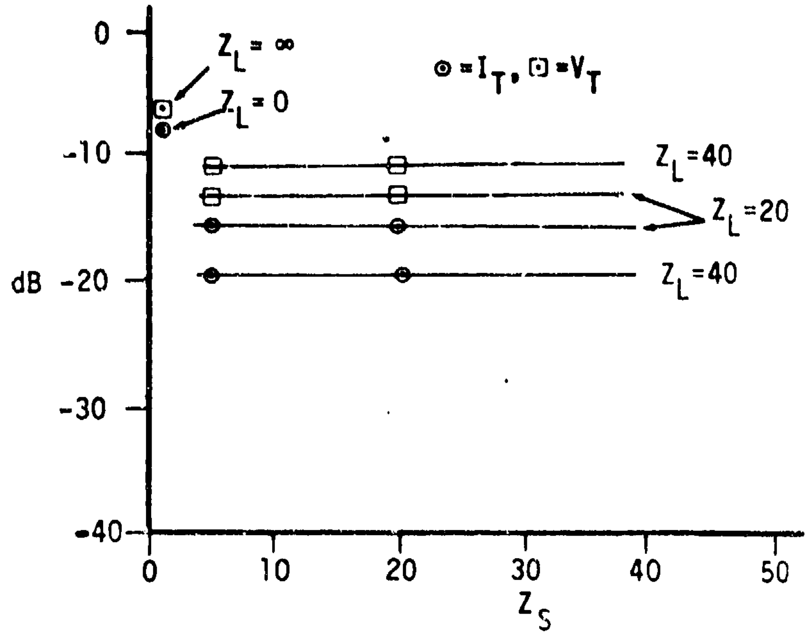


FIGURE 31	MODE 1	INPUT Y	TRANS. TFAA/FA
	SHIELD ON	OUTPUT Δ	PULSE P5

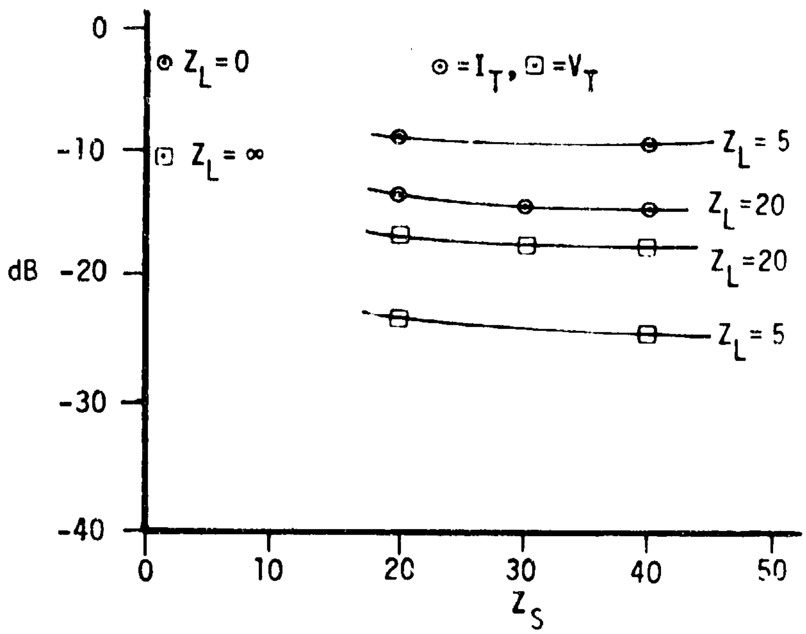


FIGURE 32	MODE 1	INPUT Δ	TRANS. TFAA/FA
	SHIELD ON	OUTPUT Y	PULSE P5

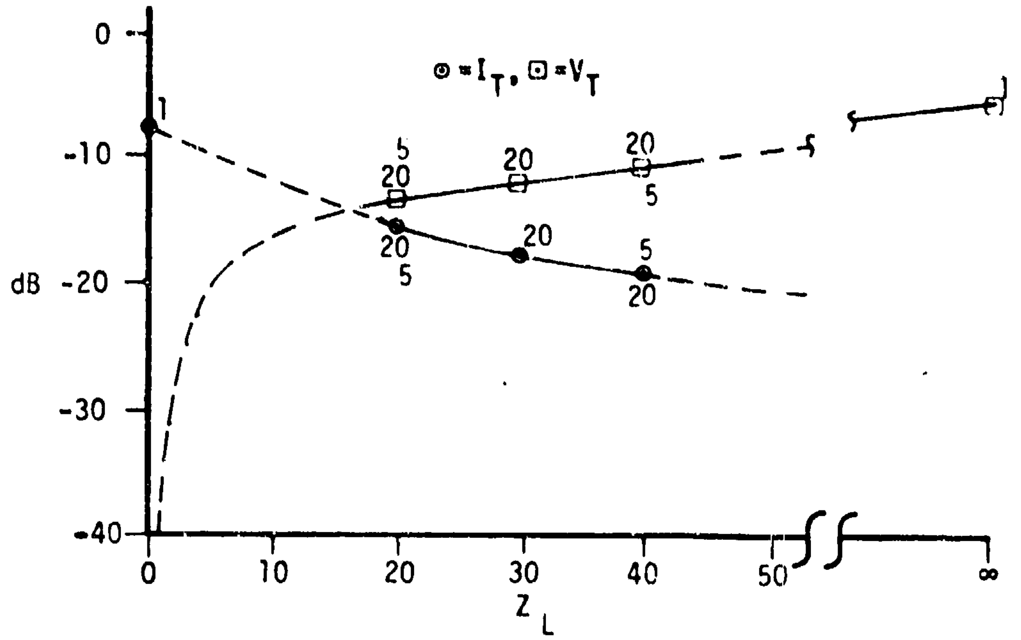


FIGURE 33 MODE 1 INPUT Y TRANS. TFAA/FA
SHIELD ON OUTPUT Δ PULSE P5

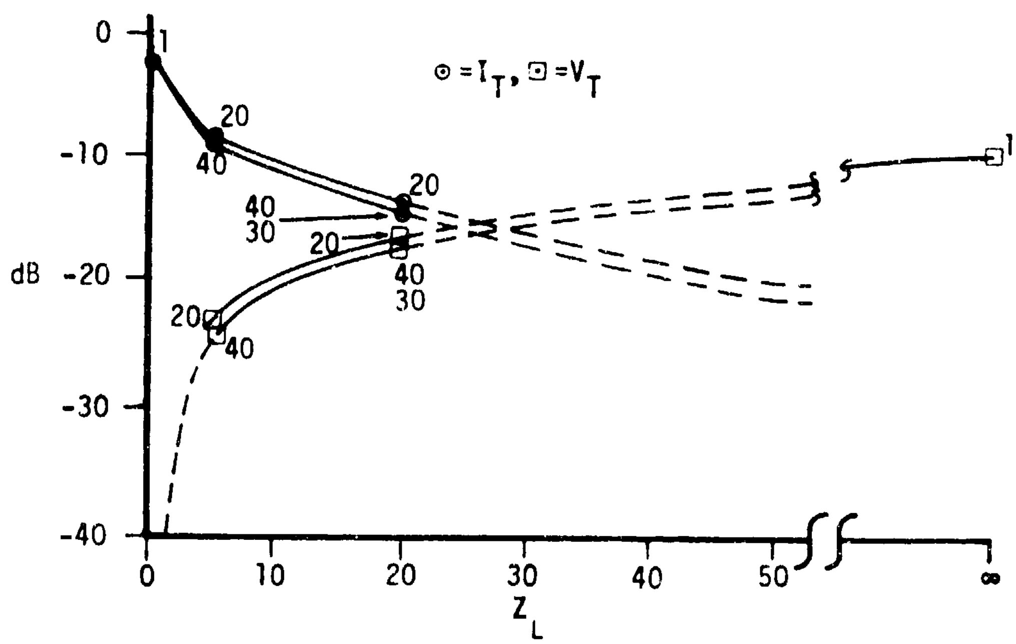


FIGURE 34 MODE 1 INPUT Δ TRANS. TFAA/FA
SHIELD ON OUTPUT Y PULSE P5

TABLE 12 TRANSFORMER TFAA/FA

MODE: 1
INPUT: COM. Y
COMPUTER RUN: A0001652

SHIELD: OFF
OUTPUT: COM. [illegible]
DATA: INVERSE SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-0.26	-121.59	-62.60	P4
2A	1	.001	-88.01	-9.84	-55.75	
3A	20	30	-7.49	-8.68	-10.09	
4A	5	30	-6.54	-11.25	-12.95	
5A						
6A						
7A						
8A						
1B	1	10^7	-2.34	-114.90	-53.93	P5
2B	1	.001	-89.83	-7.34	-41.32	
3B	20	30	-7.16	-10.07	-3.41	
4B	5	30	-7.11	-11.25	-4.04	
5B						
6B						
7B						
8B						

TABLE 13 TRANSFORMER TFAA/FA

MODE: 1
INPUT: COM. A
COMPUTER RUN: A0001656
FBLU3004

SHIELD: OFF
OUTPUT: COM. Y
DATA: INVERSE SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-1.43	-113.66	-44.29	P4
2A	1	.001	-88.04	-2.25	-37.18	
3A	30	20	-12.46	-5.32	+0.41	
4A	30	5	-21.79	-2.63	+0.47	
5A						
6A						
7A						
8A						
1B	1	10^7	-3.67	-114.87	-44.97	P5
2B	1	.001	-89.90	-2.72	-37.69	
3B	30	20	-10.79	-6.31	-0.60	
4B	30	5	-19.47	-3.36	-2.05	
5B						
6B						
7B						
8B						

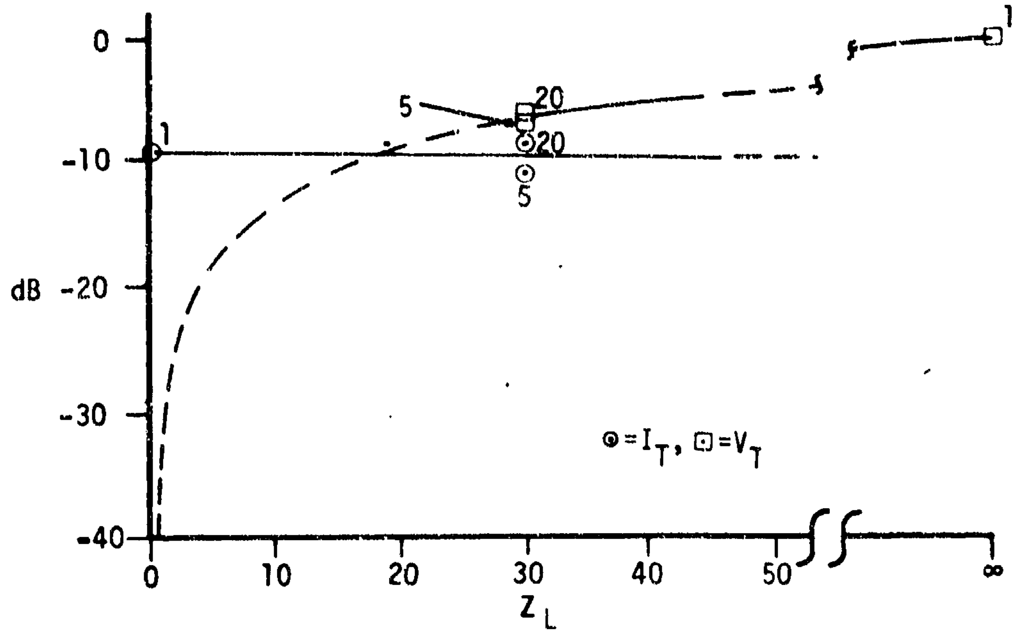


FIGURE 35 MODE 1 INPUT Y TRANS. TFAA/FA
SHIELD OFF OUTPUT Δ PULSE P4

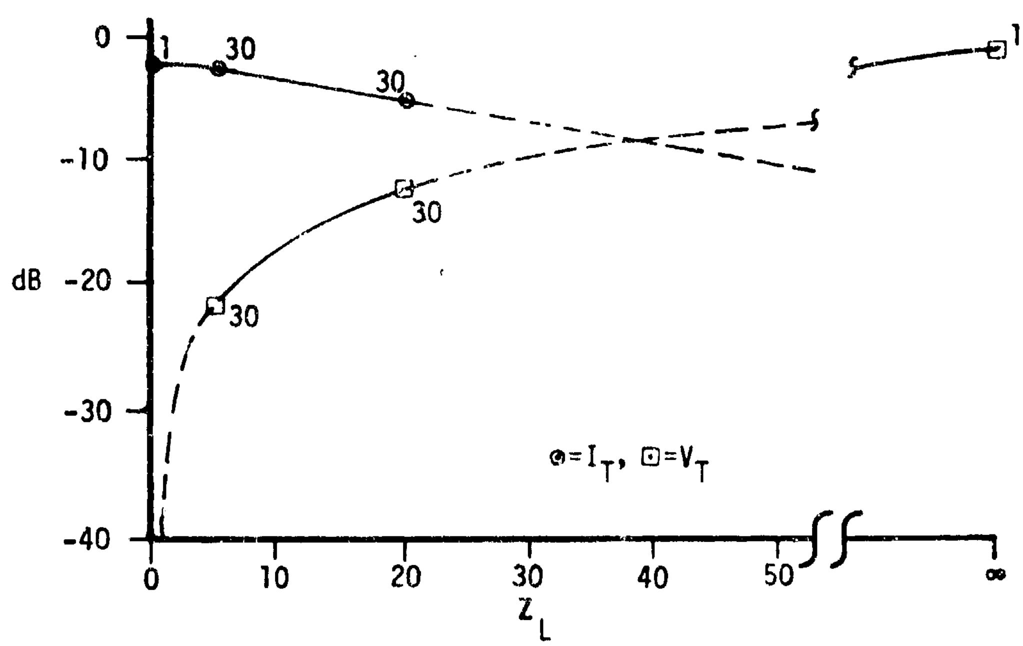


FIGURE 36 MODE 1 INPUT Δ TRANS. TFAA/FA
SHIELD OFF OUTPUT Y PULSE P4

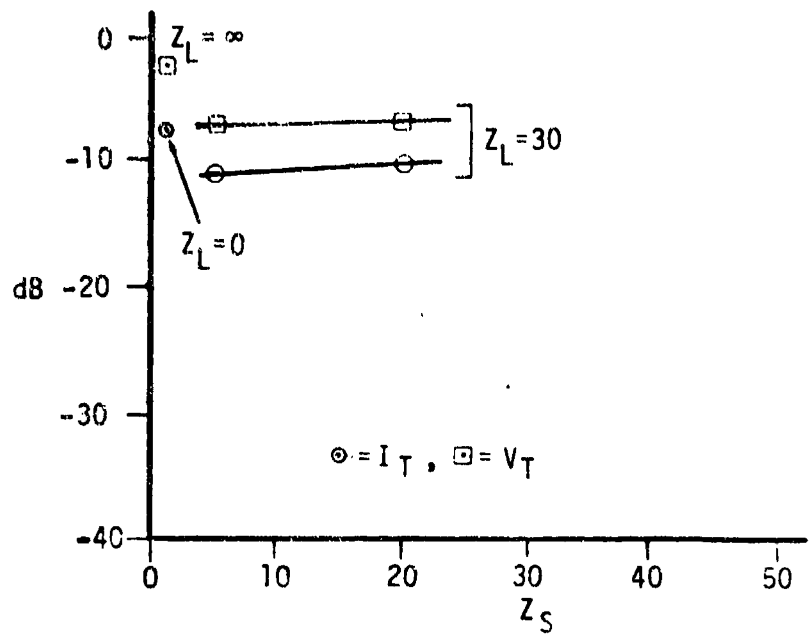


FIGURE 37	MODE	1	INPUT	Y	TRANS.	TFAA/FA
	SHIELD	OFF	OUTPUT	Δ	PULSE	P5

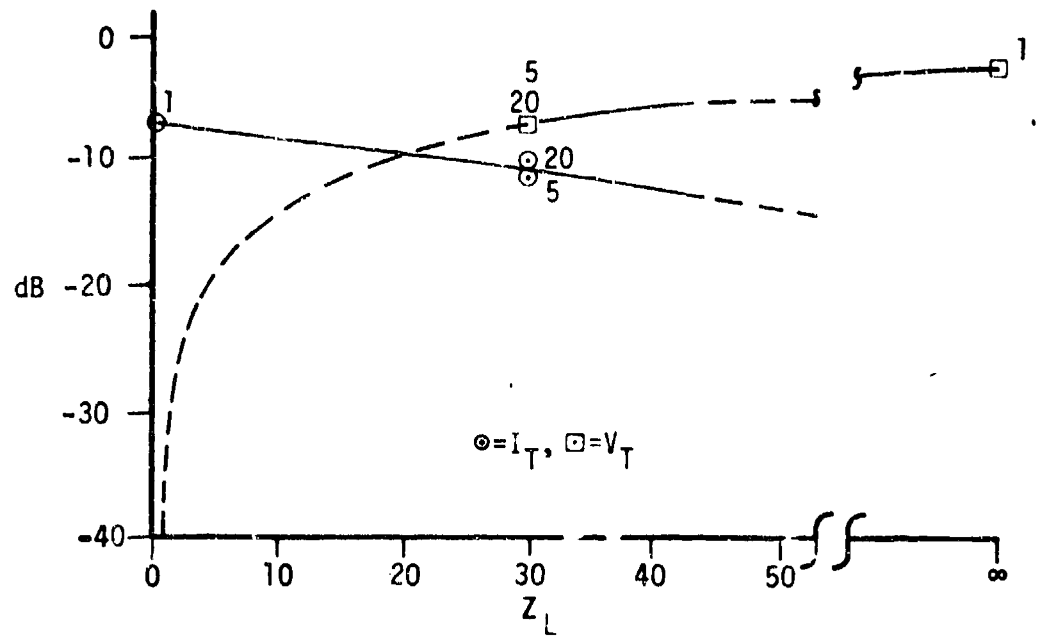


FIGURE 38 MODE 1 INPUT Y TRANS. TFAA/FA
SHIELD OFF OUTPUT Δ PULSE P5

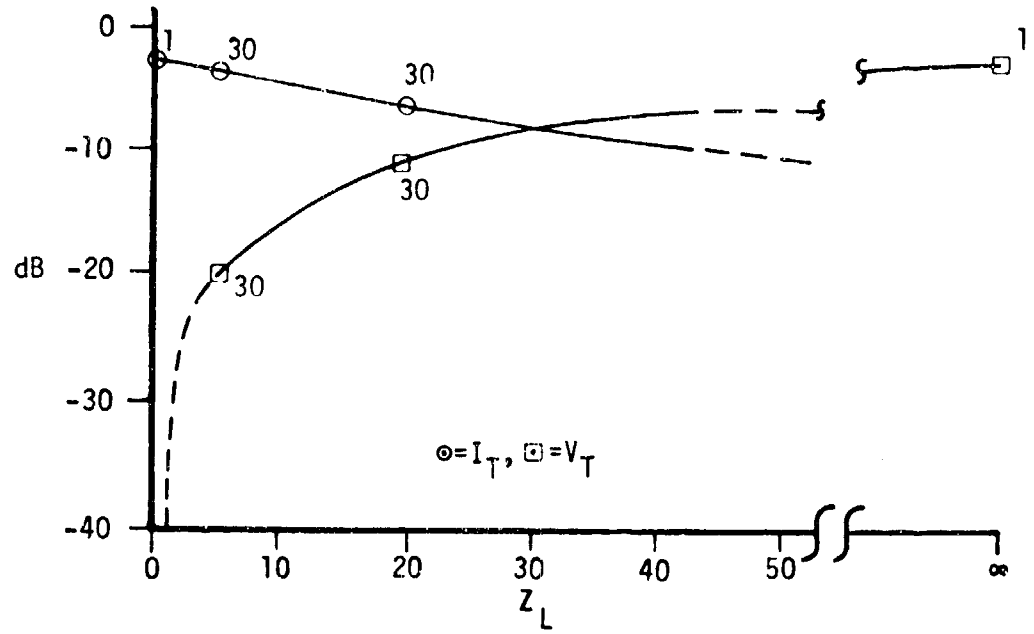


FIGURE 39 MODE 1 INPUT Δ TRANS. TFAA/FA.
SHIELD OFF OUTPUT Y PULSE P5

TABLE 14 TRANSFORMER TFAA/FA

MODE: 2 SHIELD: ON
INPUT: COM. Y OUTPUT: COM. A
COMPUTER RUN: ARED3016 DATA: INVERSE SHAKER
ARED3038

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-5.20	-123.55	-49.51	P4
2A	0	.001	-88.44	-8.95	-38.09	
3A	30	20	-19.94	-16.55	-8.46	
4A	5	30	-13.14	-18.83	-3.26	
5A						
6A						
7A						
8A						
1B	0	10^7	-6.43	-123.65	-49.80	P5
2B	0	.001	-89.45	-8.19	-37.90	
3B	30	20	-15.03	-15.75	-4.48	
4B	5	30	-12.16	-17.90	-1.80	
5B						
6B						
7B						
8B						

TABLE 15 TRANSFORMER TFAA/FA

MODE: 2 SHIELD: ON
INPUT: COM. Δ OUTPUT: COM. Y
COMPUTER RUN: ARED2091 DATA: INVERSE SHAKER
A0003941

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-9.64	-122.14	-56.20	P4
2A	0	.001	-88.49	-2.02	-31.95	
3A	30	20	-21.49	-14.44	-5.09	
4A	30	5	-27.76	-9.07	-4.46	
5A						
6A						
7A						
8A						
1B	0	10^7	-9.70	-120.74	-56.49	P5
2B	0	.001	-89.45	-1.40	-31.99	
3B	30	20	-17.36	-13.80	-1.57	
4B	30	5	-24.10	-8.73	-2.91	
5B						
6B						
7B						
8B						

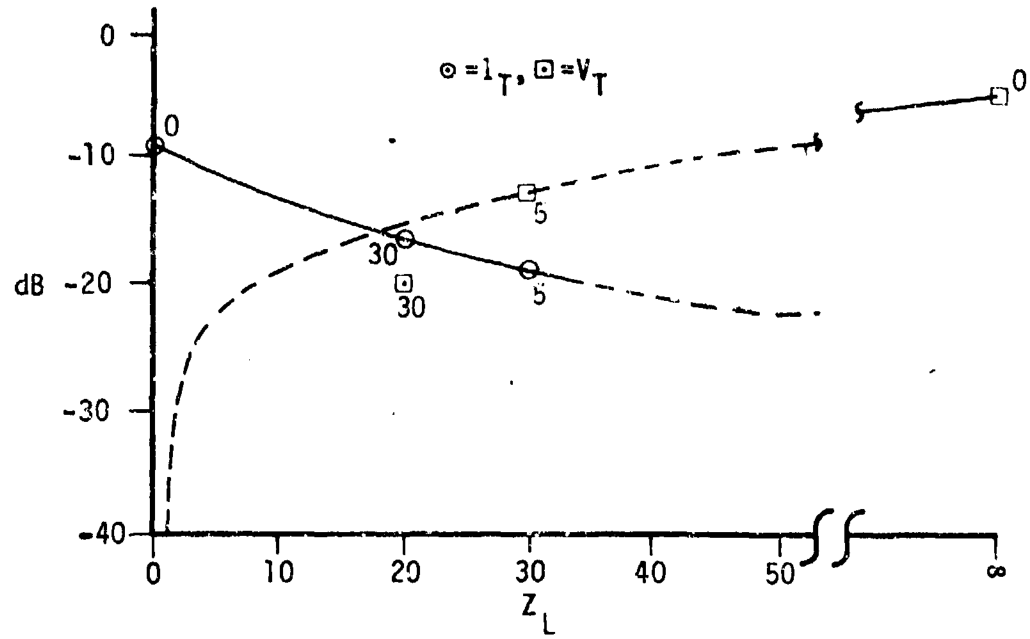


FIGURE 40 MODE 2 INPUT Y TRANS. TFAA/FA
SHIELD ON OUTPUT Δ PULSE P4

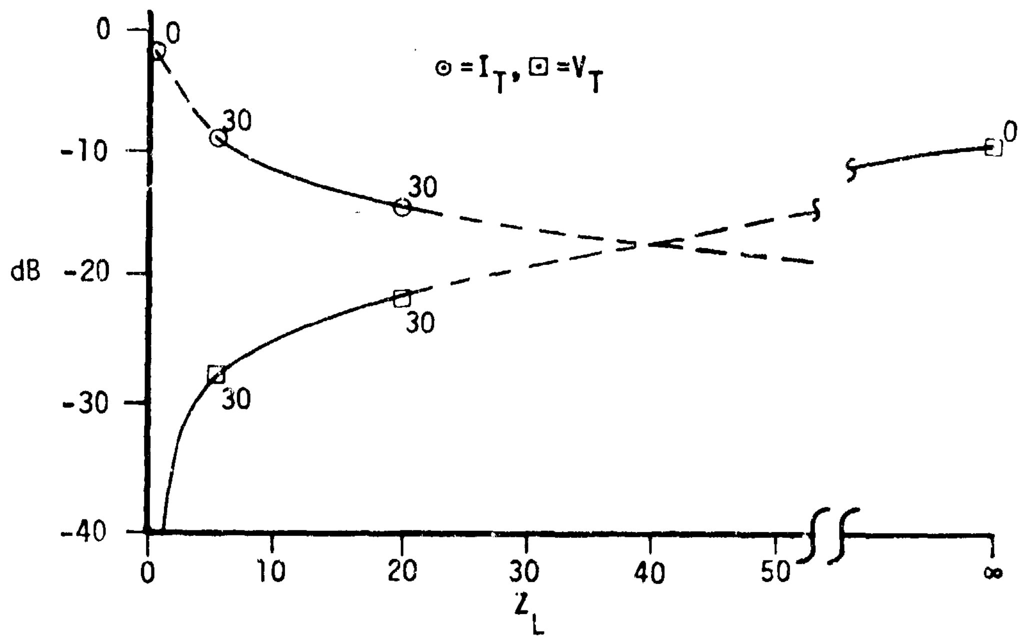


FIGURE 41 MODE 2 INPUT Δ TRANS. TFAA/FA
SHIELD ON OUTPUT Y PULSE P4

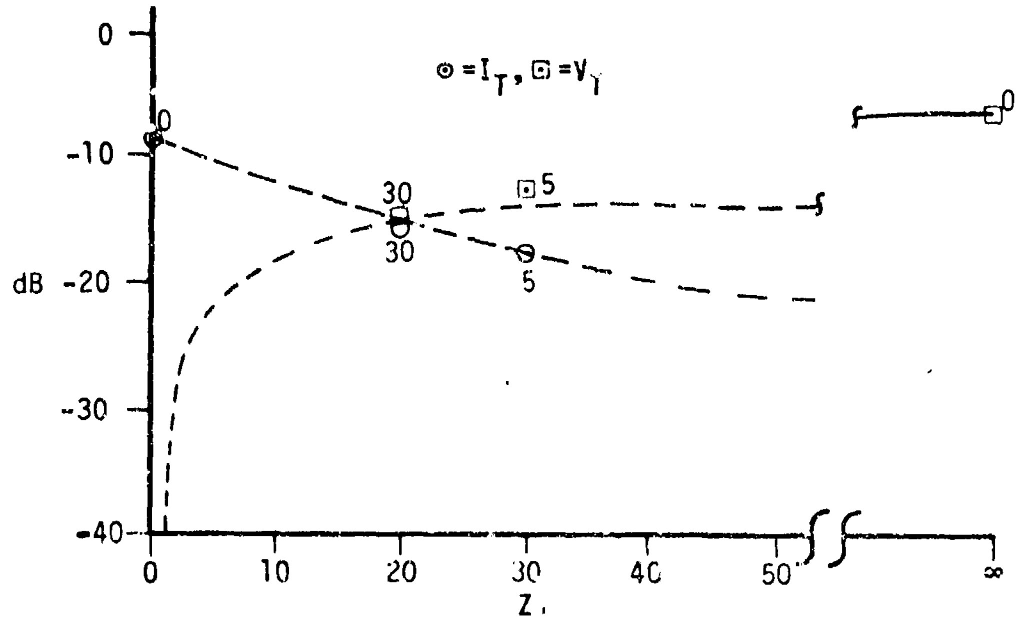


FIGURE 42 MODE 2 INPUT Y TRANS. TFAA/FA
SHIELD ON OUTPUT Δ PULSE P5

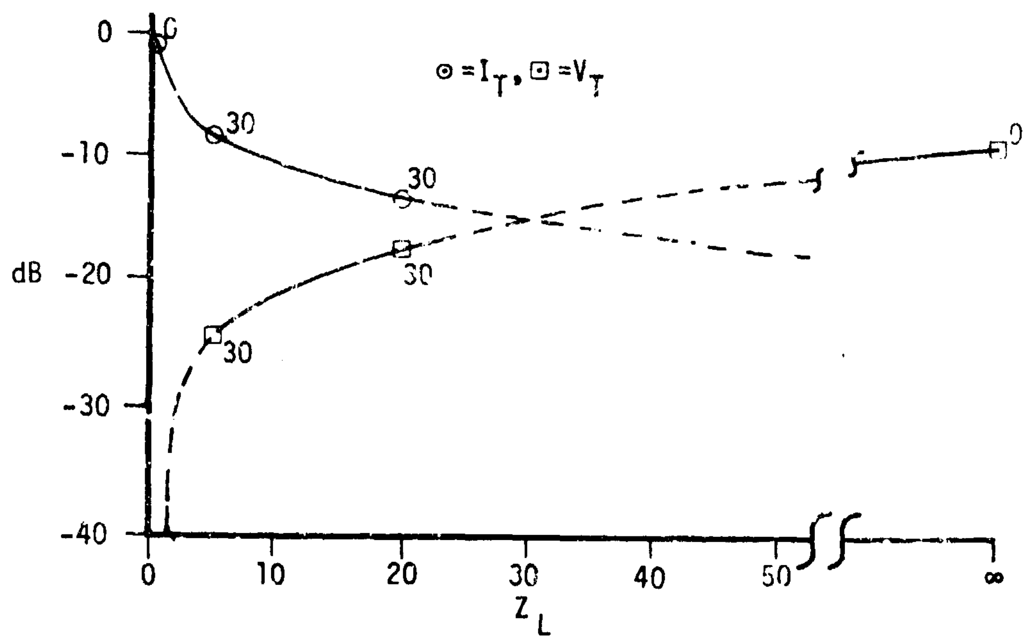


FIGURE 43 MODE 2 INPUT Δ TRANS. TFAA/FA
SHIELD ON OUTPUT Y PULSE P5

TABLE 16 TRANSFORMER TFAA/FA

MODE: 2 SHIELD: OFF
INPUT: COM. Y OUTPUT: COM. Δ
COMPUTER RUN: FBLU3006 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-0.04	-115.44	-42.26	P4
2A	0	.001	-88.50	-6.33	-38.50	
3A	20	30	-7.62	-7.82	-0.28	
4A	5	30	-6.31	-10.24	-1.10	
5A						
6A						
7A						
8A						
1B	0	10^7	-2.21	-116.80	-50.77	P5
2B	0	.001	-89.76	-6.58	-38.97	
3B	20	30	-6.69	-10.01	-0.45	
4B	5	30	-7.77	-12.16	-1.67	
5B						
6B						
7B						
8B						

TABLE 17 TRANSFORMER TFAA/FA

MODE: 2 SHIELD: OFF
INPUT: COM. [illegible] OUTPUT: COM. Y
COMPUTER RUN: FBLU3005 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-2.19	-113.24	-43.87	P4
2A	0	.001	-88.50	-2.67	-37.26	
3A	30	20	-11.02	-4.23	-0.45	
4A	30	5	-21.13	-2.26	-1.75	
5A						
6A						
7A						
8A						
1B	0	10^7	-4.22	-114.73	-51.77	P5
2B	0	.001	-89.76	-2.71	-37.66	
3B	30	20	-10.40	-6.44	-0.78	
4B	30	5	-19.56	-4.31	-2.48	
5B						
6B						
7B						
8B						

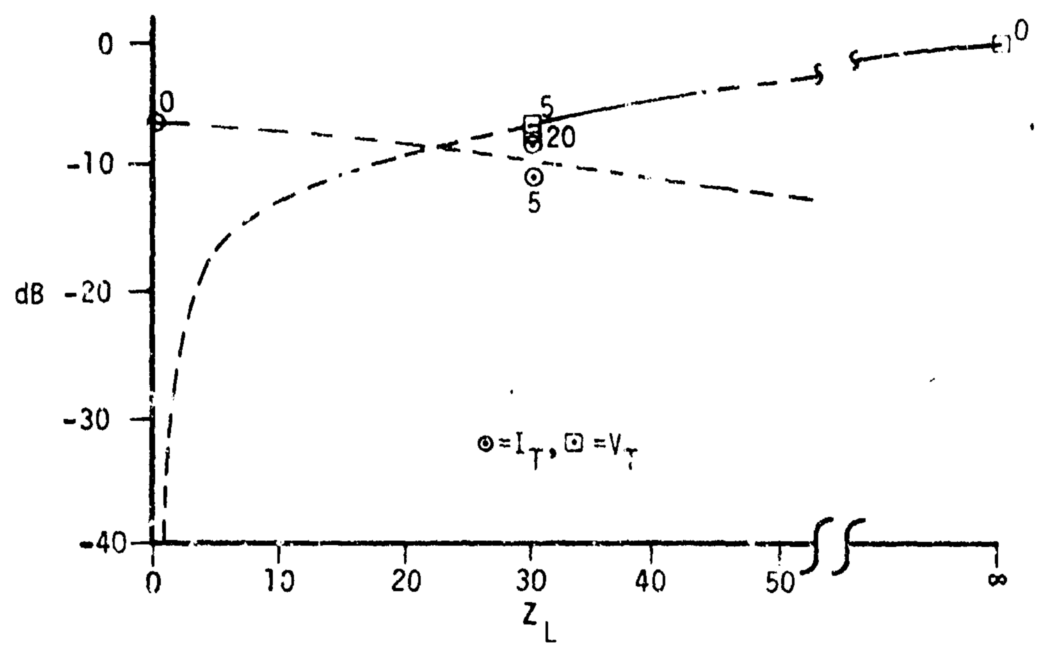


FIGURE 44	MODE 2	INPUT Y	TRANS. TFAA/FA
	SHIELD OFF	OUTPUT Δ	PULSE P4

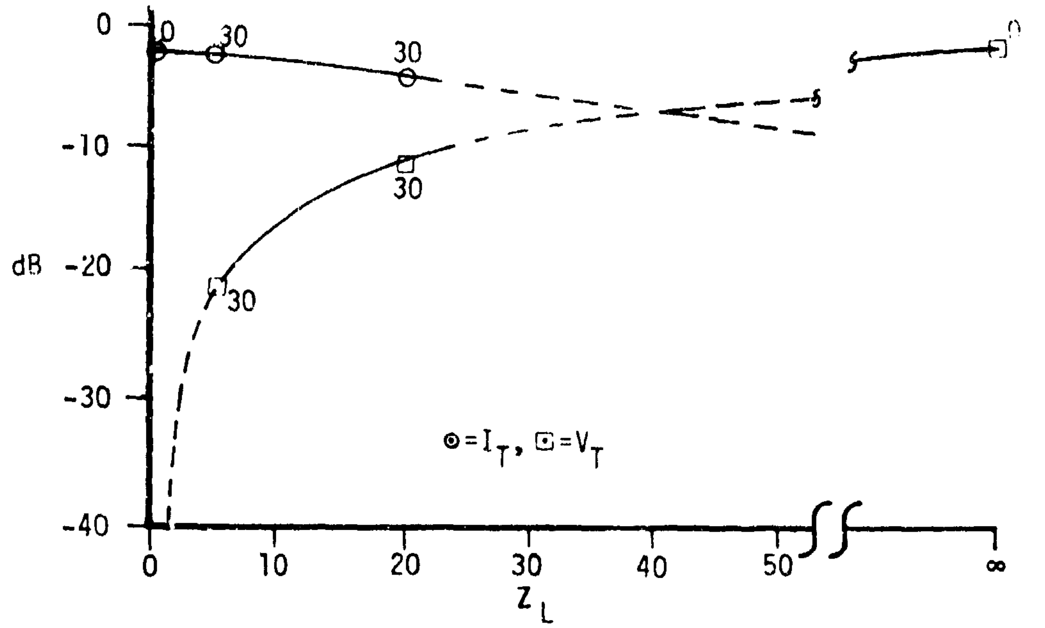


FIGURE 45	MODE 2	INPUT Δ	TRANS. TFAA/FA
	SHIELD OFF	OUTPUT Y	PULSE P4

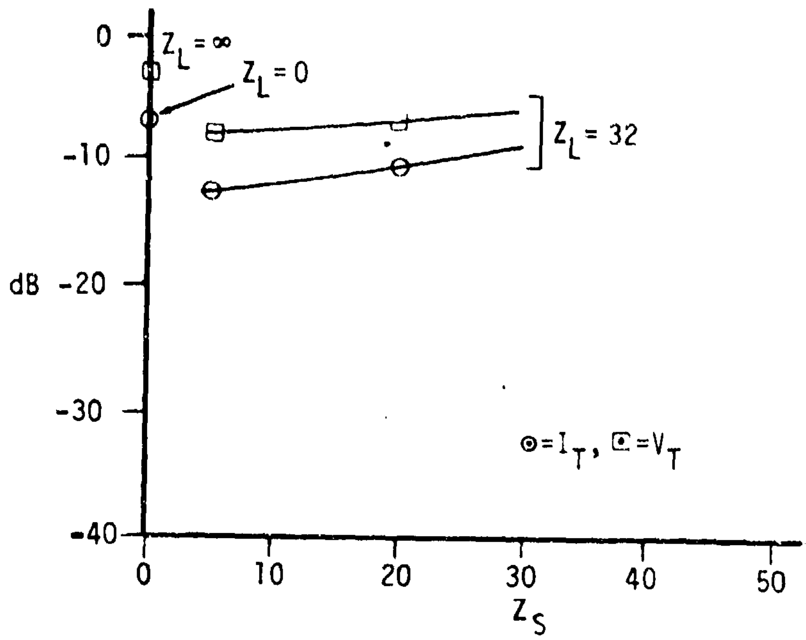


FIGURE 46	MODE	2	INPUT	Y	TRANS.	TFAA/FA
	SHIELD	OFF	OUTPUT	Δ	PULSE	P5

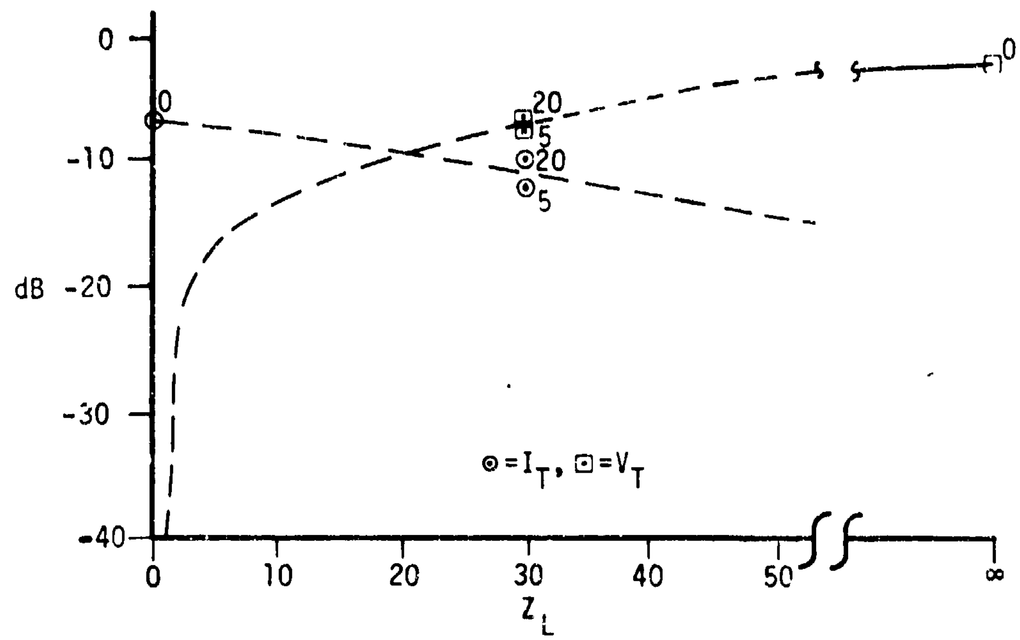


FIGURE 47	MODE	2	INPUT	Y	TRANS.	TFAA/FA
	SHIELD	OFF	OUTPUT	Δ	PULSE	P5

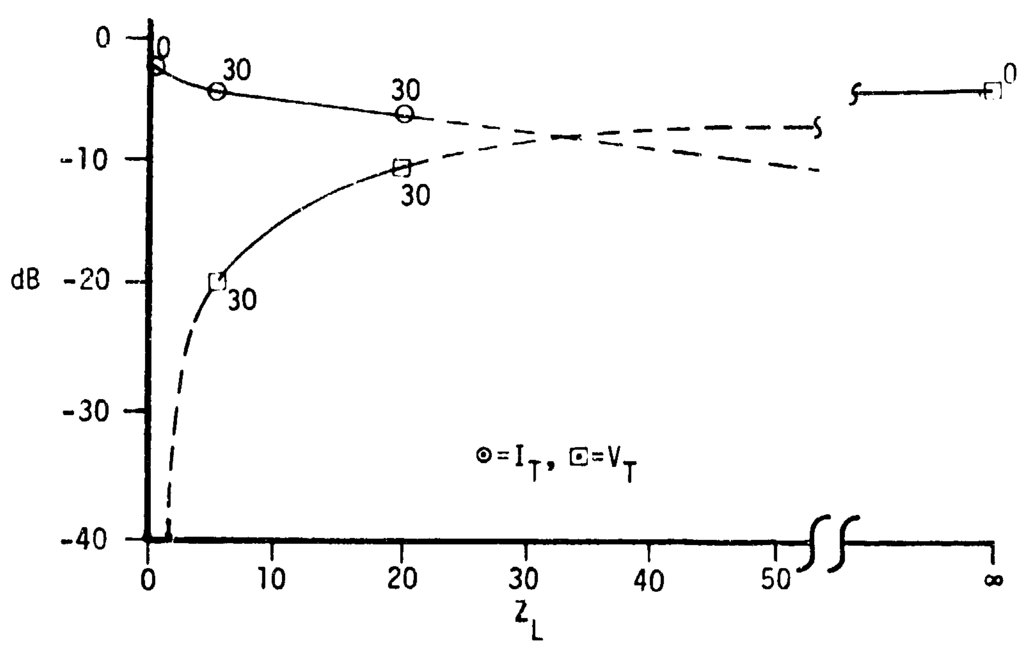


FIGURE 48	MODE	2	INPUT	Δ	TRANS.	TFAA/FA
	SHIELD	OFF	OUTPUT	Y	PULSE	P5

TABLE 18 TRANSFORMER TFAA/FA

MODE: 3	SHIELD: ON
INPUT: COM. Y	OUTPUT: DIF. A
COMPUTER RUN: F0001820 ARED2092	DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-18.88	-141.94	-74.17	P4
2A	1	.001	-113.87	-36.92	-78.11	
3A	20	5	-45.98	-32.59	-38.53	
4A	20	20	-36.83	-35.47	-34.78	
5A	40	5	-47.11	-32.18	-38.28	
6A	40	20	-37.04	-35.04	-34.73	
7A						
8A						
1B	1	10^7	-23.53	-140.27	-73.40	P5
2B	1	.001	-113.79	-30.53	-64.80	
3B	20	5	-41.47	-30.41	-30.19	
4B	20	20	-31.24	-32.22	-27.85	
5B	40	5	-40.78	-30.2[illegible]	-30.51	
6B	40	20	-30.72	-32.22	-28.31	
7B						
8B						

TABLE 19 TRANSFORMER TFAA/FA

MODE: 3	SHIELD: ON
INPUT: DIF. A	OUTPUT: COM. Y
COMPUTER RUN: F0001821 F0003387	DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-29.11	-151.12	-94.86	P4
2A	1	.001	-113.40	-35.41	-76.13	
3A	5	20	-35.09	-36.13	-39.77	
4A	20	20	-37.90	-33.78	-36.38	
5A	5	40	-33.02	-40.08	-40.21	
6A	20	40	-35.80	-37.70	-37.03	
7A						
8A						
1B	1	10^7	-29.01	-141.21	-79.45	P5
2B	1	.001	-113.80	-26.01	-60.80	
3B	5	20	-35.01	-31.52	-28.95	
4B	20	20	-34.52	-29.78	-28.88	
5B	5	40	-32.35	-34.88	-29.18	
6B	20	40	-32.03	-33.31	-29.24	
7B						
8B						

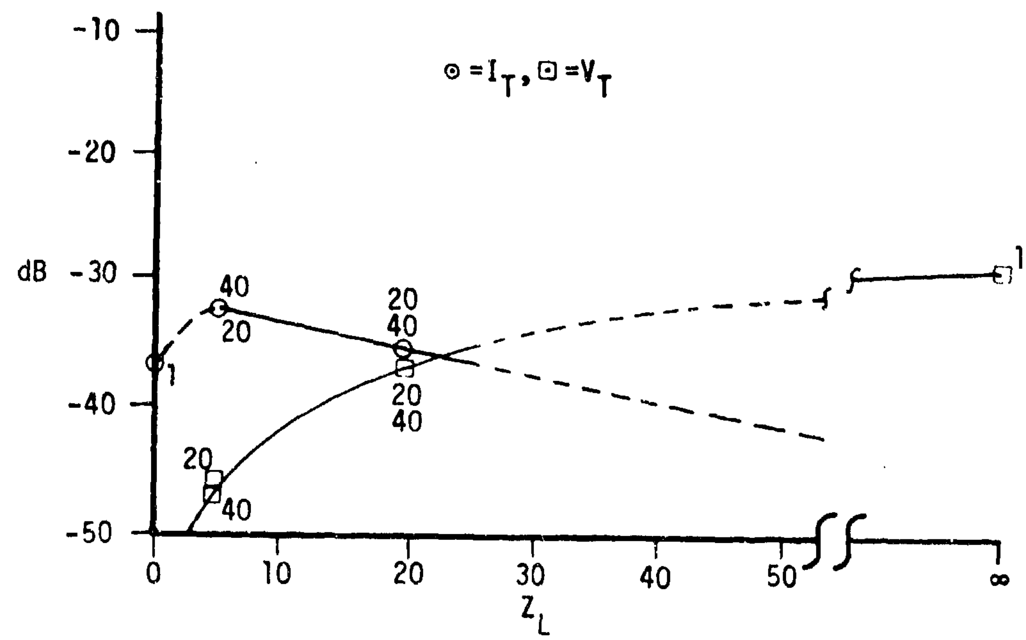


FIGURE 49 MODE 3 INPUT Y TRANS. TFAA/FA
SHIELD ON OUTPUT Δ PULSE P4

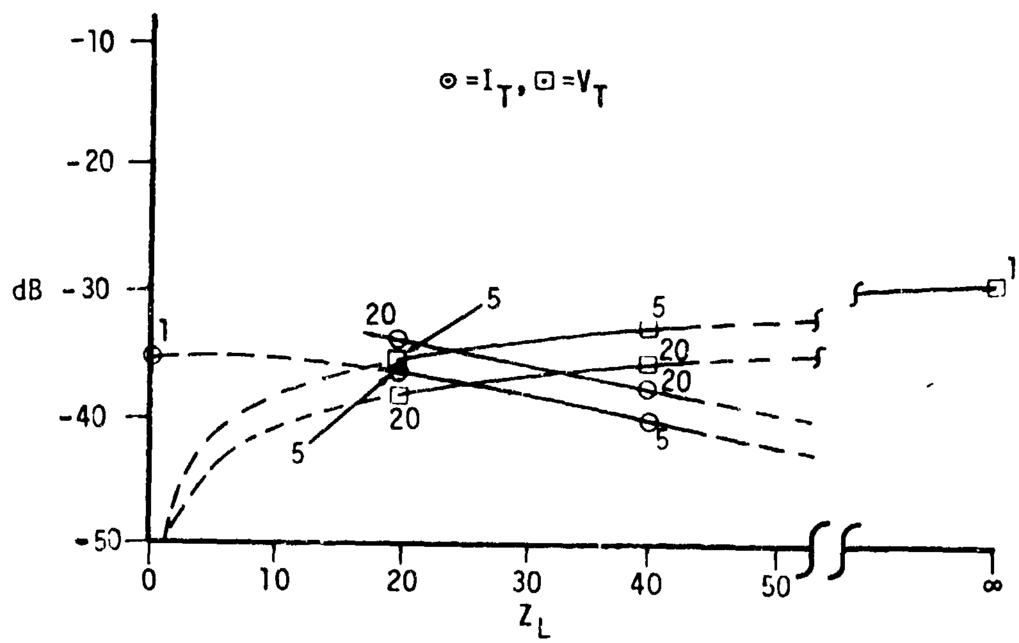


FIGURE 50 MODE 3 INPUT Δ TRANS. TFAA/FA
SHIELD ON OUTPUT Y PULSE P4

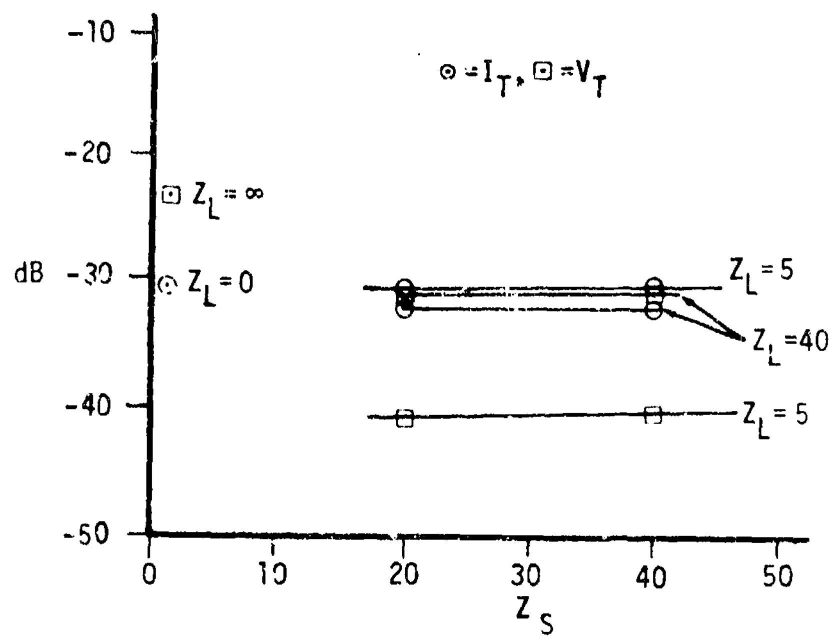


FIGURE 51	MODE 3	INPUT Y	TRANS. TFAA/FA
	SHIELD ON	OUTPUT Δ	PULSE P5

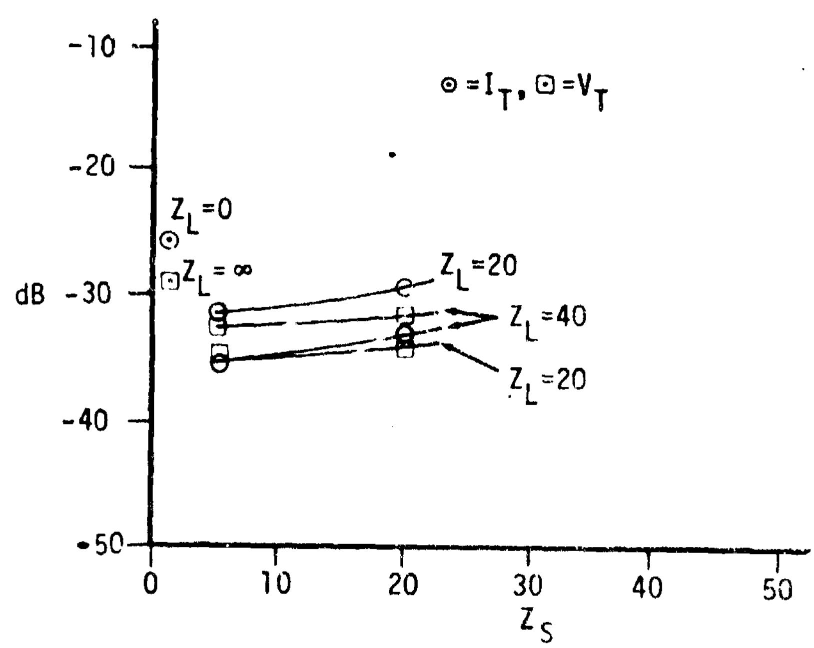


FIGURE 52	MODE 3	INPUT Δ	TRANS. TFAA/FA
	SHIELD ON	OUTPUT Y	PULSE P5

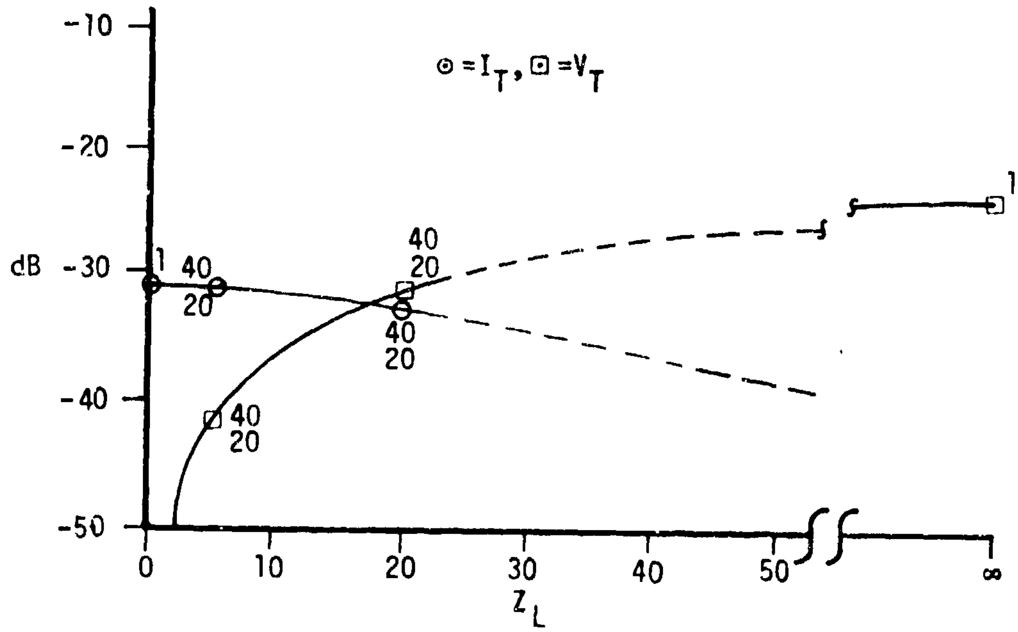


FIGURE 53	MODE	3	INPUT	Y	TRANS.	TFAA/FA
	SHIELD	ON	OUTPUT	Δ	PULSE	P5

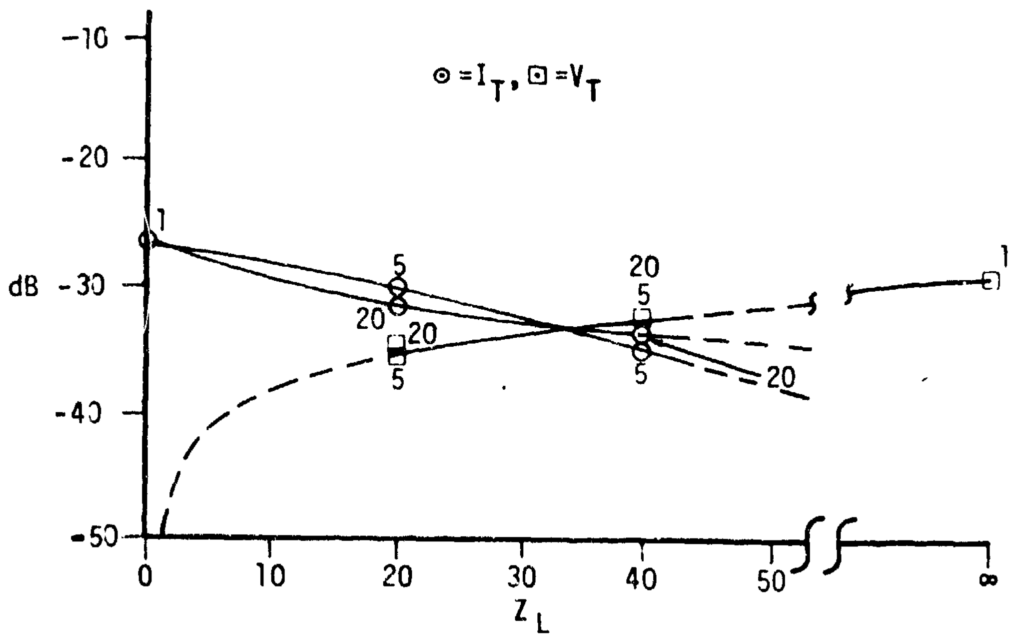


FIGURE 54	MODE	3	INPUT	Δ	TRANS.	TFAA/FA
	SHIELD	ON	OUTPUT	Y	PULSE	P5

TABLE 20 TRANSFORMER TF1004

MODE: 1 SHIELD: ON
INPUT: COM. Y OUTPUT: COM. Δ
COMPUTER RUN: F0003398 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-16.06	-138.52	-81.98	P4
2A	1	.001	-97.97	-20.24	-65.81	
3A	10	20	-26.17	-24.81	-21.70	
4A	30	20	-29.60	-25.00	-23.44	
5A	10	40	-24.13	-28.80	-22.50	
6A	30	40	-26.85	-28.27	-23.48	
7A	10	0	-760.0	-16.09	-380.0	
8A	30	30	-27.87	-26.80	-23.43	
1B	1	10^7	-16.79	-132.95	-67.42	P5
2B	1	.001	-98.49	-14.24	-50.24	
3B	10	20	-23.30	-23.30	-15.35	
4B	30	20	-23.78	-22.60	-17.53	
5B	10	40	-20.94	-22.96	-16.37	
6B	30	40	-21.52	-26.33	-18.10	
7B	10	0	-760.0	-14.87	-380.0	
8B	30	30	-22.33	-24.66	-17.80	

TABLE 21 TRANSFORMER TF1004

MODE: 1	SHIELD: ON
INPUT: COM. Δ	OUTPUT: COM. Y
COMPUTER RUN: F0003397	DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-17.78	-133.09	-66.39	P4
2A	1	.001	-98.47	-13.63	-46.93	
3A	20	10	-32.47	-21.66	-16.67	
4A	20	30	-28.21	-26.93	-17.37	
5A	40	10	-35.76	-21.85	-19.15	
6A	40	30	-30.79	-26.41	-19.09	
7A	0	10	-24.32	-19.94	-13.39	
8A	30	30	-29.64	-26.62	-18.33	
1B	1	10^7	-16.40	-131.52	-66.69	P5
2B	1	.001	98.43	-13.37	-46.16	
3B	20	10	-28.07	-20.88	-13.95	
4B	20	30	-22.85	-25.21	-15.02	
5B	40	10	-29.59	-21.03	-15.09	
6B	40	30	-24.44	-25.43	-15.70	
7B	0	10	-24.09	-19.22	-12.74	
8B	30	30	-23.83	-25.34	-15.40	

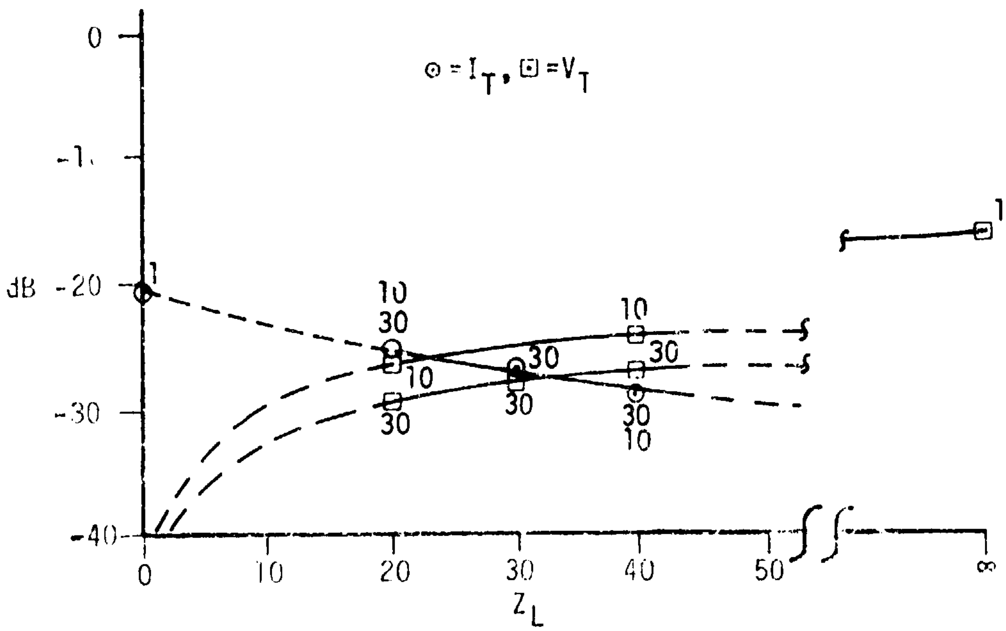


FIGURE 55 MODE 1 INPUT Y TRANS. TF1004
SHIELD ON OUTPUT Δ PULSE P4

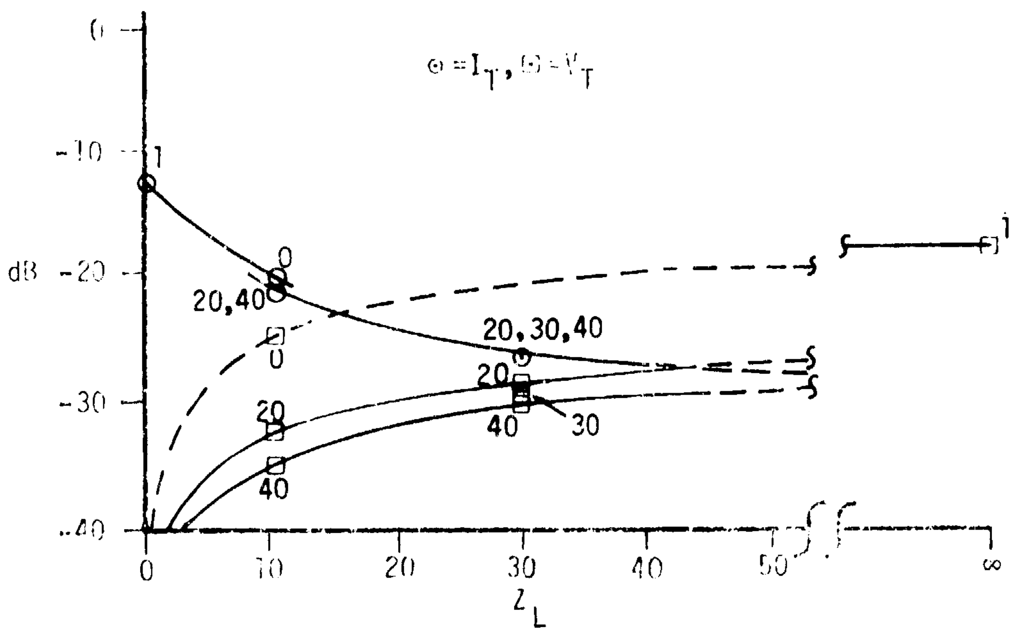


FIGURE 56 MODE 1 INPUT Δ TRANS. TF1004
SHIELD ON OUTPUT Y PULSE P4

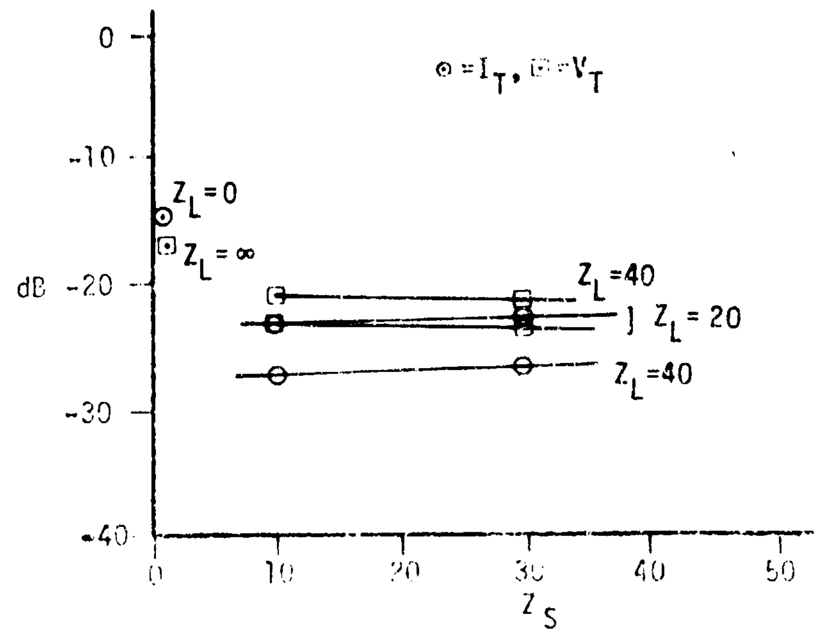


FIGURE 57 MODE 1 INPUT Y TRANS. TF1004
SHIELD ON OUTPUT Δ PULSE P5

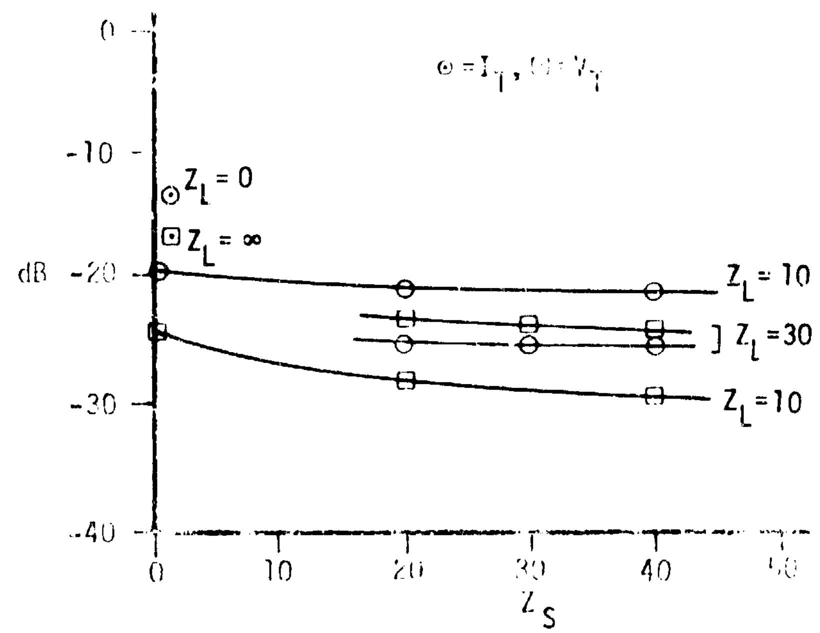


FIGURE 58 MODE 1 INPUT Δ TRANS. TF1004
SHIELD ON OUTPUT Y PULSE P5

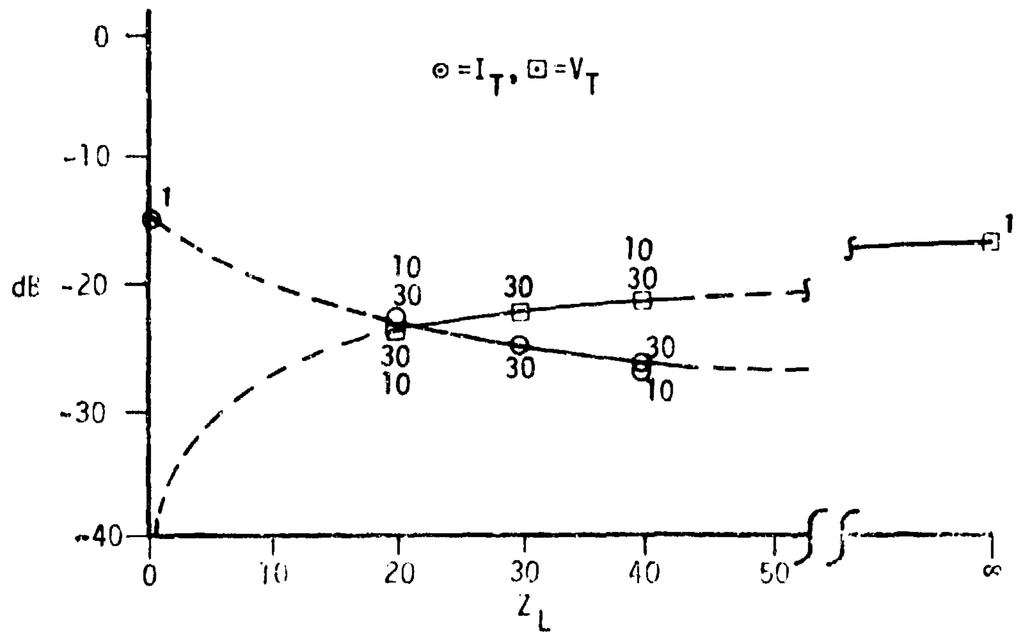


FIGURE 59 MODE 1 INPUT Y TRANS. TF1004
SHIELD ON OUTPUT Δ PULSE P5

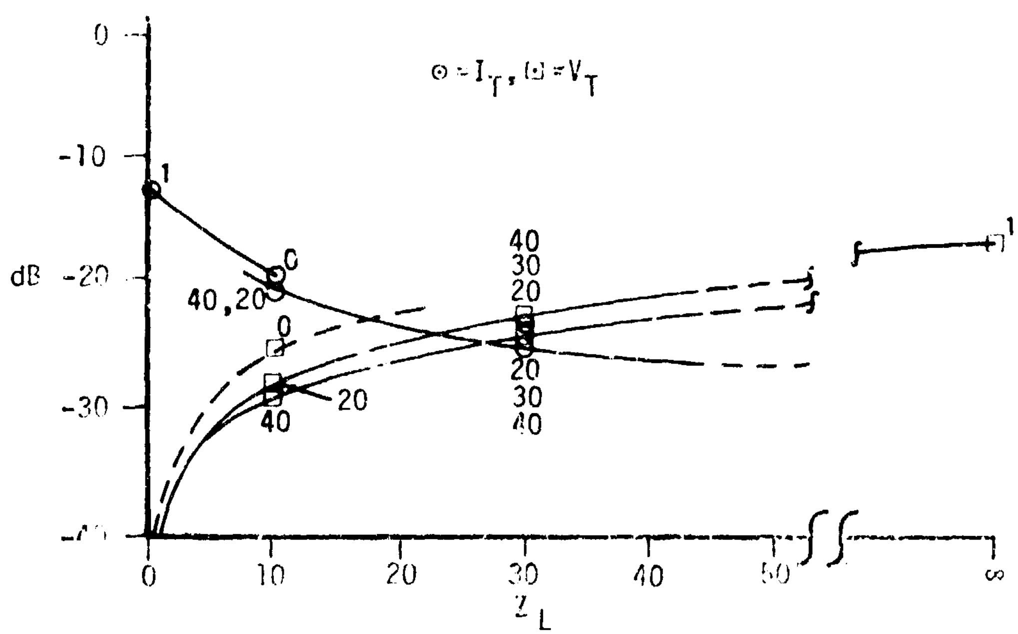


FIGURE 60 MODE 1 INPUT Δ TRANS. TF1004
SHIELD ON OUTPUT Y PULSE P5

TABLE 22 TRANSFORMER TF1004

MODE: 2	SHIELD: ON
INPUT: COM. Y	OUTPUT: COM. Δ
COMPUTER RUN: F0003389	DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-17.62	-133.71	-65.67	P4
2A	0	.001	-99.82	-15.89	-50.24	
3A	10	20	-27.16	-24.64	-15.25	
4A	30	20	-31.42	-25.05	-18.05	
5A	10	40	-25.38	-28.86	-15.94	
6A	30	40	-28.84	-28.50	-18.75	
7A	10	0	-760.0	-16.46	-380.0	
8A	30	30	-29.78	-26.94	-18.33	
1B	0	10^7	-16.65	-132.08	-65.92	P5
2B	0	.001	-99.94	-15.30	-49.94	
3B	10	20	-22.05	-23.42	-14.25	
4B	30	20	-25.04	-23.75	-14.97	
5B	10	40	-19.68	-27.04	-14.97	
6B	30	40	-22.78	-27.48	-15.74	
7B	10	0	-760.0	-15.99	-380.0	
8B	30	30	-23.60	-25.81	-15.3	

TABLE 23 TRANSFORMER TF1004

MODE: Z
INPUT: COM. [illegible]
COMPUTER RUN: F0003388

SHIELD: ON
OUTPUT: COM. Y
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-17.74	-132.89	-67.78	P4
2A	0	.001	-99.82	-15.07	-48.77	
3A	20	10	-32.59	-21.63	-17.04	
4A	20	30	-28.40	-26.97	-18.43	
5A	40	10	-36.15	-22.17	-19.07	
6A	40	30	-31.18	-26.73	-20.48	
7A	0	10	-24.78	-20.00	-15.02	
8A	30	30	-29.96	-26.83	-19.50	
1B	0	10^7	-17.32	-132.12	-67.74	P5
2B	0	.001	-99.94	-14.78	-48.37	
3B	20	10	-27.79	-20.28	-14.98	
4B	20	30	-23.11	-25.14	-16.34	
5B	40	10	-29.33	-20.52	-15.66	
6B	40	30	-24.75	-25.50	-17.07	
7B	0	10	-24.60	-19.43	-14.59	
8B	30	30	-24.13	-25.36	-16.71	

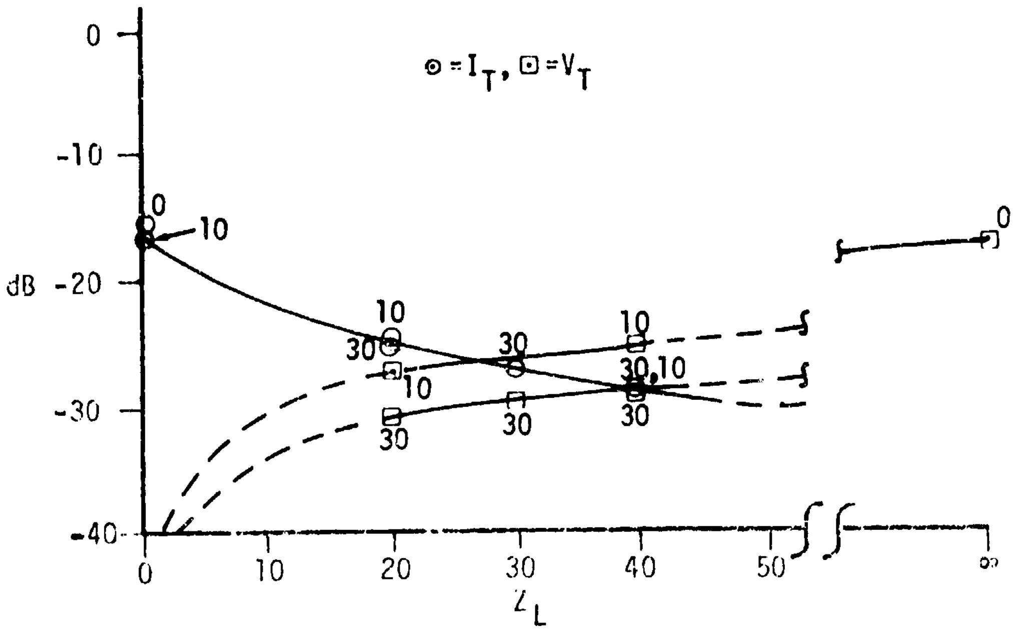


FIGURE 61 MODE 2 INPUT Y TRANS. TF1004
SHIELD ON OUTPUT Δ PULSE P4

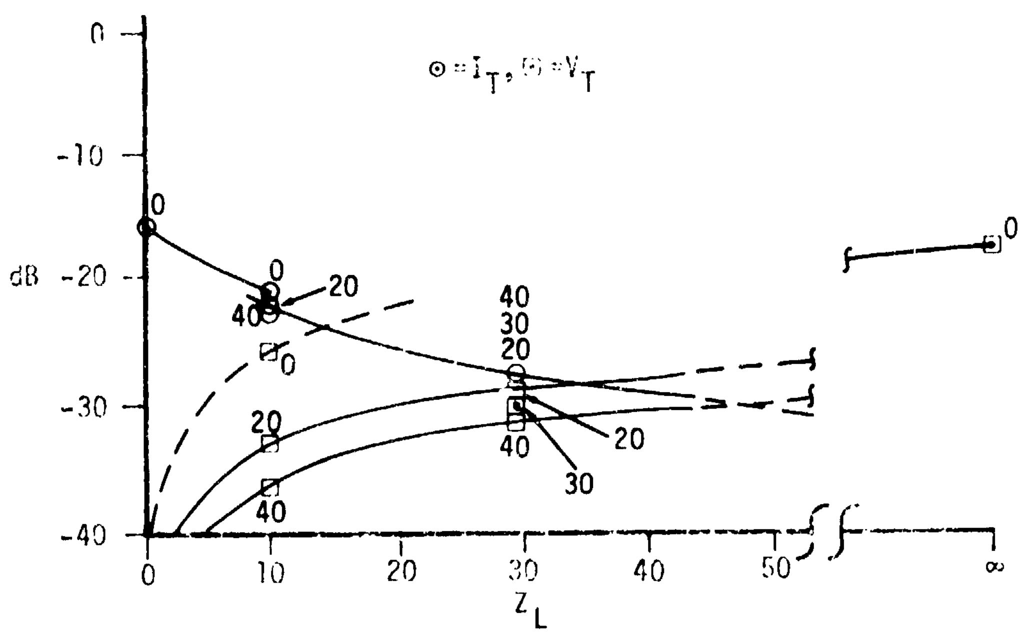


FIGURE 62 MODE 2 INPUT Δ TRANS. TF1004
SHIELD ON OUTPUT Y PULSE P4

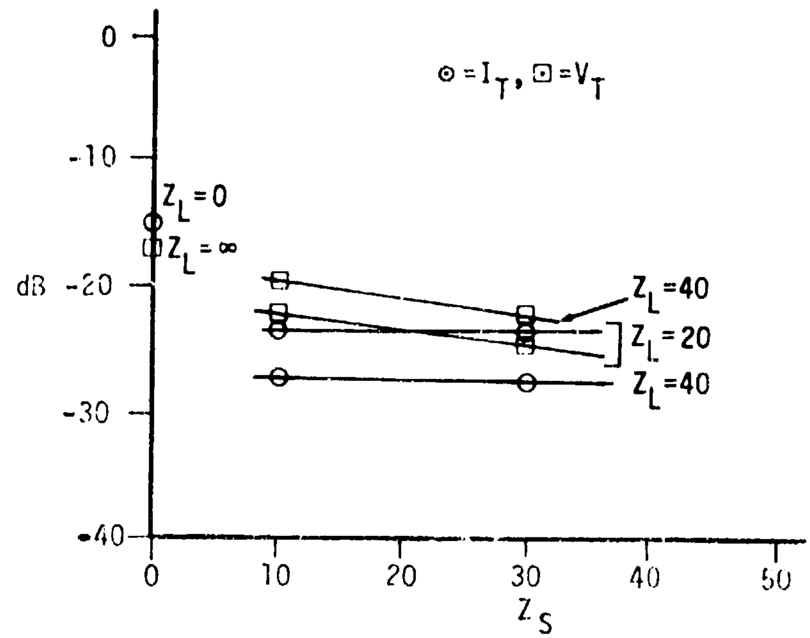


FIGURE 63 MODE 2 INPUT Y TRANS. TF1004
SHIELD ON OUTPUT Δ PULSE P5

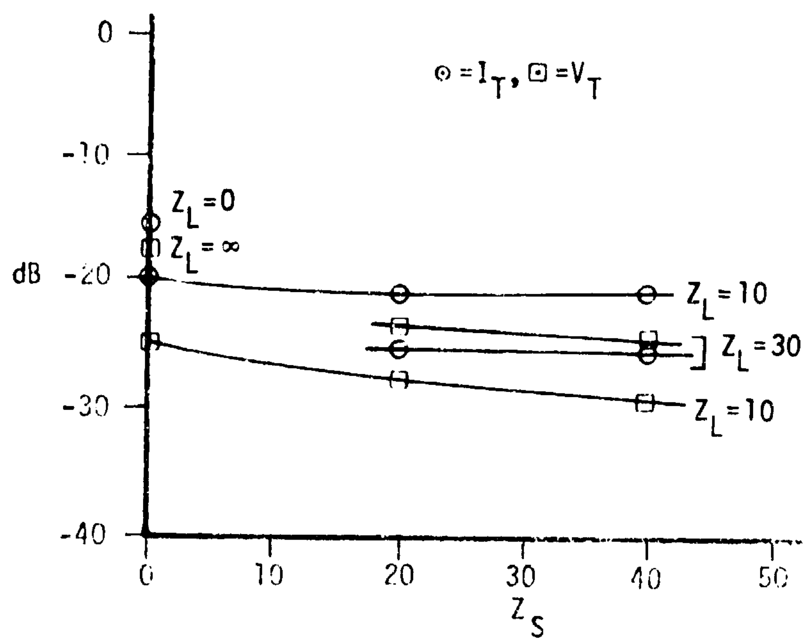


FIGURE 64 MODE 2 INPUT Δ TRANS. TF1004
SHIELD ON OUTPUT Y PULSE P5

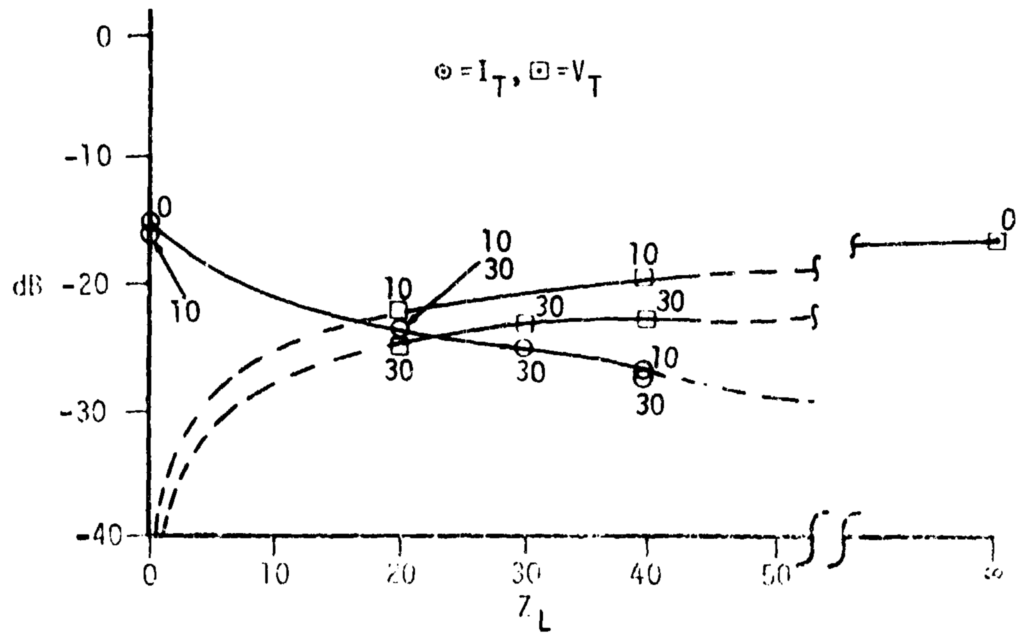


FIGURE 65 MODE 2 INPUT Y TRANS. TF1004
SHIELD ON OUTPUT Δ PULSE P5

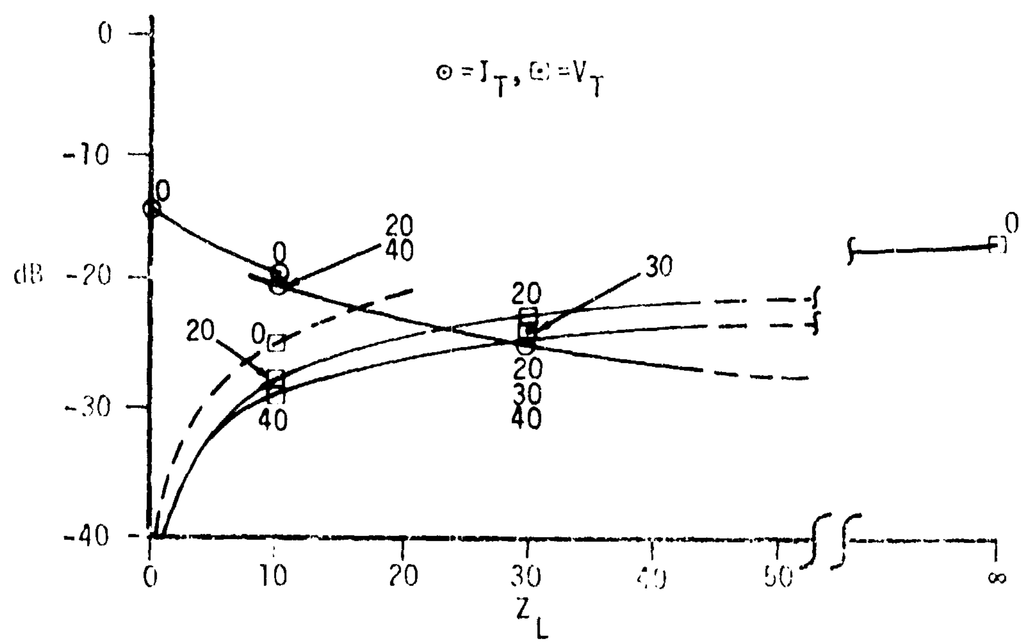


FIGURE 66 MODE 2 INPUT Δ TRANS. TF1004
SHIELD ON OUTPUT Y PULSE P5

TABLE 24 TRANSFORMER TF1004

MODE: EQUIVALENT TO MODE 2
INPUT: COM. Δ EQUIVALENT
COMPUTER RUN: A0001659
A0001661

SHIELD: ON
OUTPUT: COM. Y EQUIVALENT
DATA: SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-20.99	-140.90	-52.57	P4
2A	1	.001	-96.43	-16.48	-40.44	
3A	0	10	-22.33	-26.80	-10.81	
4A	20	10	-30.27	-20.90	-2.44	
5A						
6A						
7A						
8A						
1B	1	10^7	-19.83	-143.40	-58.88	P5
2B	1	.001	-92.80	-16.48	-43.45	
3B	0	10	-22.33	-26.80	-10.81	
4B	20	10	-27.18	-23.29	+1.19	
5B	20	5	-30.39	-20.48	+1.92	
6B	20	25	-23.85	-27.90	+0.90	
7B	20	40	-22.76	-30.88	+0.91	
8B	20	.001	-100.35	-16.48	-31.52	

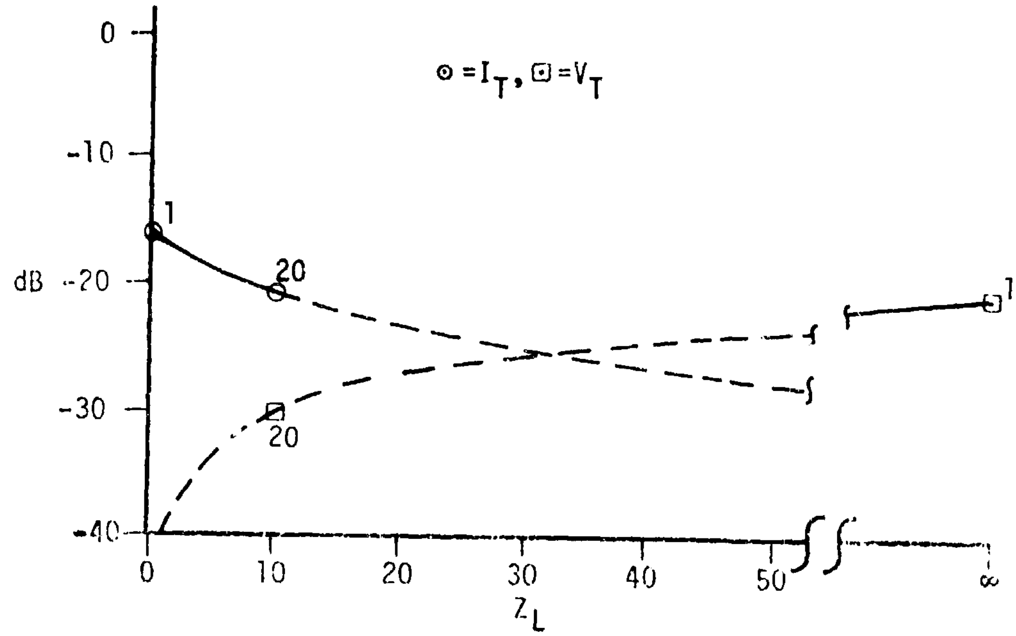


FIGURE 67 MODE 2 INPUT Δ TRANS. PI1004
SHIELD ON OUTPUT Y PULSE P4

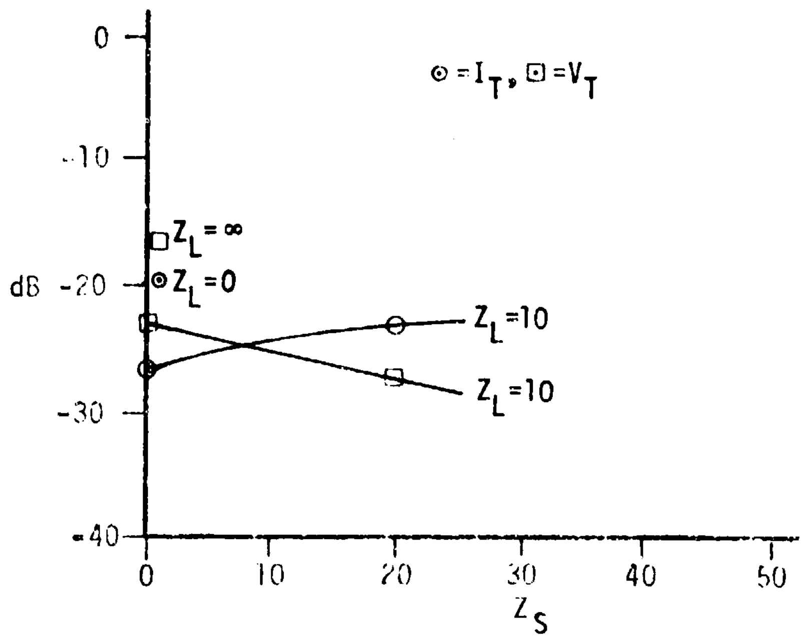


FIGURE 68	MODE 2	INPUT	Δ	TRANS.	PI1004
	SHIELD ON	OUTPUT	Y	PULSE	P5

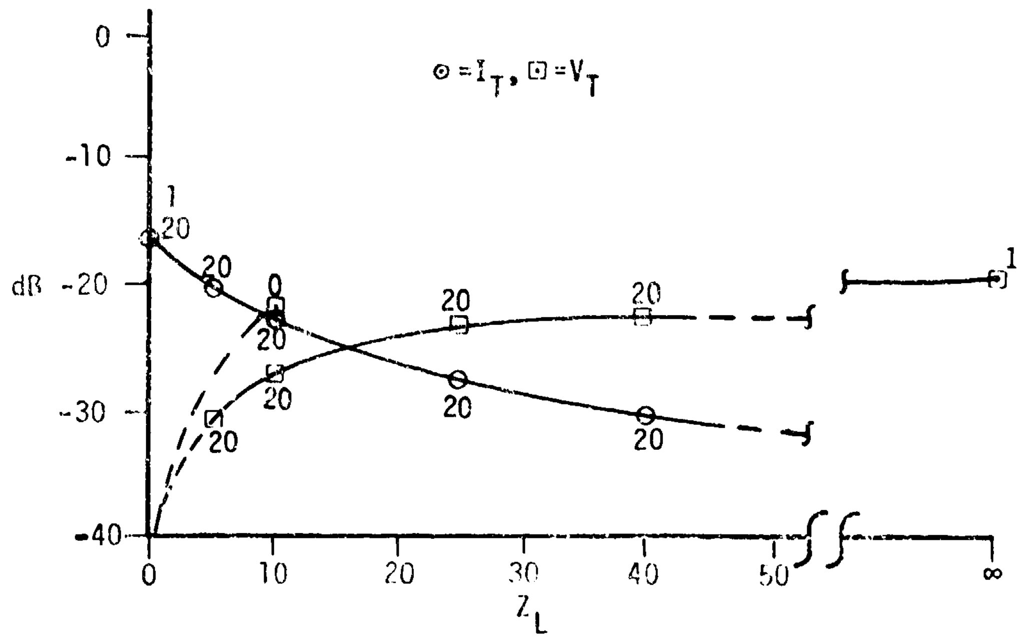


FIGURE 69	MODE	2	INPUT	Δ	TRANS.	PI1004
	SHIELD	ON	OUTPUT	Y	PULSE	P5

TABLE 25 TRANSFORMER TF1010

MODE: 1
INPUT: COM. Y
COMPUTER RUN: *ARED5066
F0003396

SHIELD: ON
OUTPUT: COM. Δ
DATA: *INVERSE SHAKER TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-5.99	-127.89	-73.61	P4
2A	1	.001	-94.38	-16.46	-66.04	
3A	20	20	-20.40	-15.36	-15.59	
4A	20	40	-17.61	-18.48	-15.17	
5A	40	20	-23.52	-16.08	-16.66	
6A	40	40	-20.74	-19.25	-16.07	
7A	30	30	-20.45	-17.44	-15.45	
8A						
1B	1	10^7	-5.98	-120.25	-57.35	P5
2B	1	.001	-94.37	-9.31	-48.73	
3B	20	20	-16.35	-14.68	-8.76	
4B	20	40	-13.16	-17.51	-8.25	
5B	40	20	-18.47	-15.58	-10.15	
6B	40	40	-15.44	-18.44	-9.49	
7B	30	30	-15.60	-16.72	-9.07	
8B*	20	2.5	-29.43	-6.60	-20.54	
9B*	20	5	-23.95	-6.63	-20.83	
10B*	20	10	-21.02	-7.77	-27.43	
11B*	20	50	-10.88	-17.23	-9.07	
12B*	5	20	-13.44	-10.58	-0.03	
13B*	20	.001	-92.46	-8.99	-41.48	
14B*	20	40	-11.70	-16.34	-8.86	

TABLE 26 TRANSFORMER TF1010

MODE: 1 SHIELD: ON
INPUT: COM. Δ OUTPUT: COM. Y
COMPUTER RUN: F0003394 DATA: TAPE
F0003395

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-13.06	-121.29	-57.20	P4
2A	1	.001	-94.72	-3.55	-43.27	
3A	20	20	-20.82	-12.07	-6.76	
4A	40	20	-24.06	-12.75	-6.80	
5A	20	40	-19.11	-16.26	-7.28	
6A	40	40	-22.39	-16.99	-7.08	
7A	30	30	-21.49	-14.77	-6.92	
8A						
1B	1	10^7	-12.43	-121.49	-57.39	P5
2B	1	.001	-94.28	-3.96	-43.02	
3B	20	20	-17.03	-12.36	-6.48	
4B	40	20	-18.15	12.61	-6.44	
5B	20	40	-15.10	-16.43	-7.01	
6B	40	40	-16.21	-16.72	-6.73	
7B	30	30	-16.36	-14.74	-6.60	
8B						

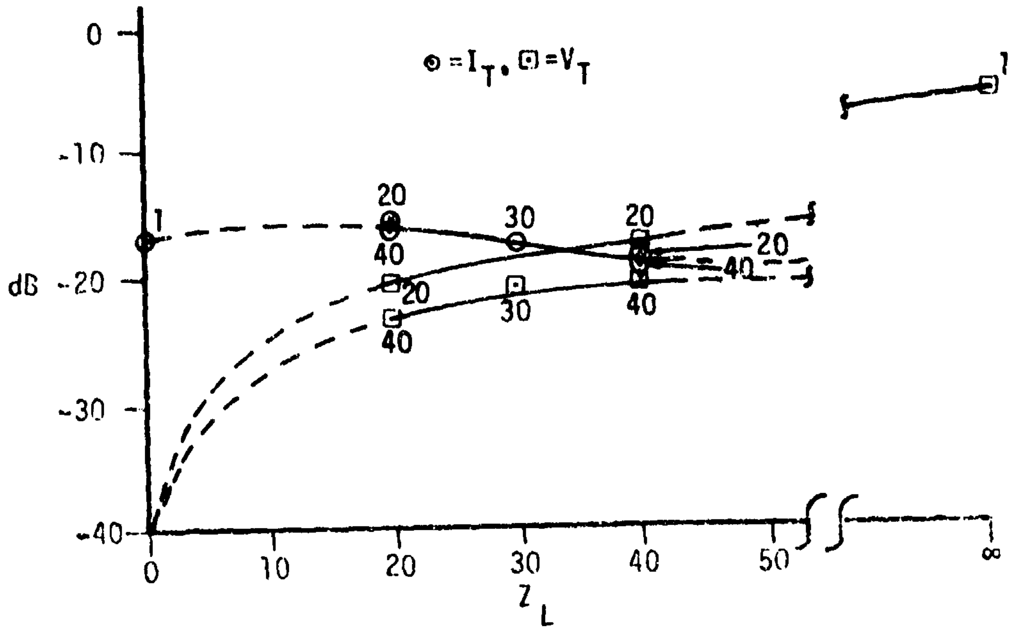


FIGURE 70	MODE	1	INPUT	Y	TRANS.	TF1010
	SHIELD	ON	OUTPUT	Δ	PULSE	P4

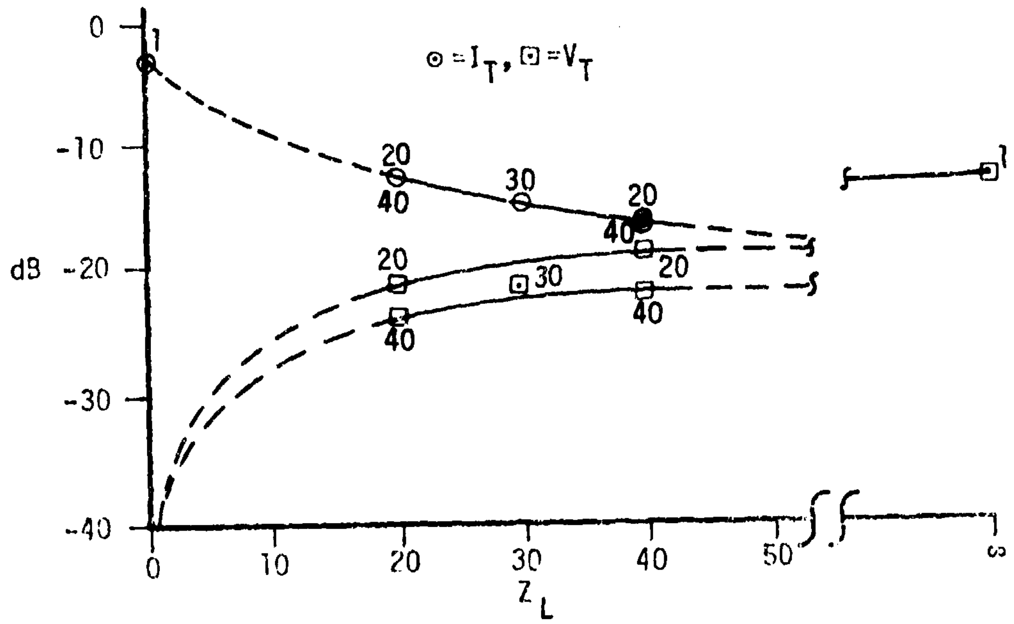


FIGURE 71	MODE	1	INPUT	Δ	TRANS.	TF1010
	SHIELD	ON	OUTPUT	Y	PULSE	P4

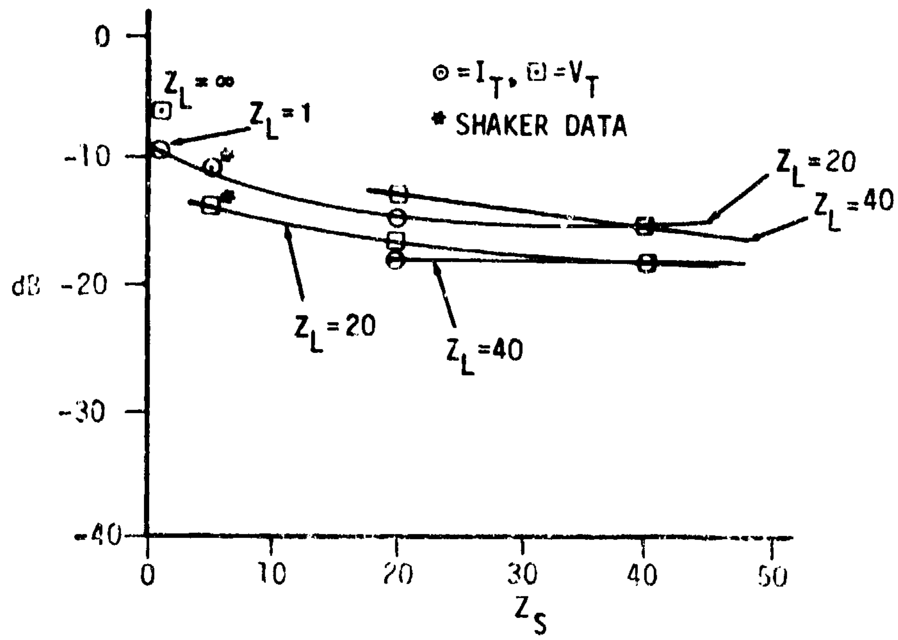


FIGURE 72 MODE 1 INPUT Y TRANS. TF1010
SHIELD ON OUTPUT Δ PULSE P5

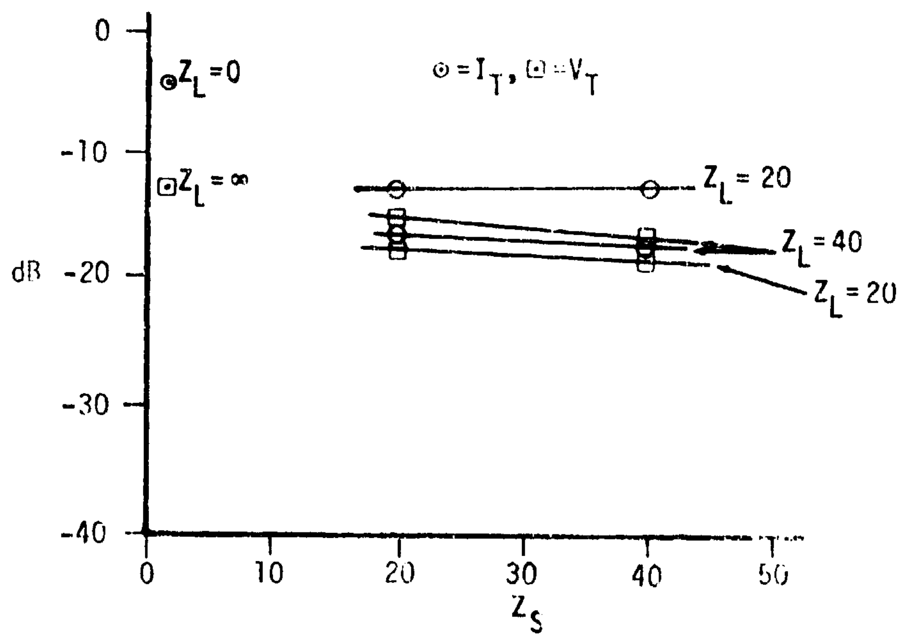


FIGURE 73 MODE 1 INPUT Δ TRANS. TF1010
SHIELD ON OUTPUT Y PULSE P5

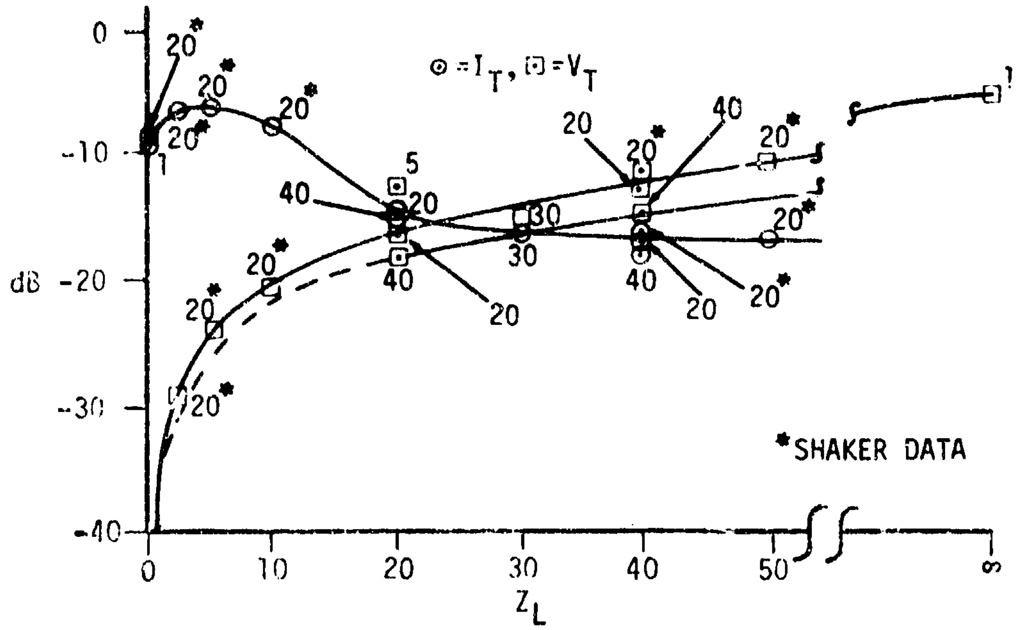


FIGURE 74 MODE 1 INPUT Y TRANS. TF1010
SHIELD ON OUTPUT Δ PULSE P5

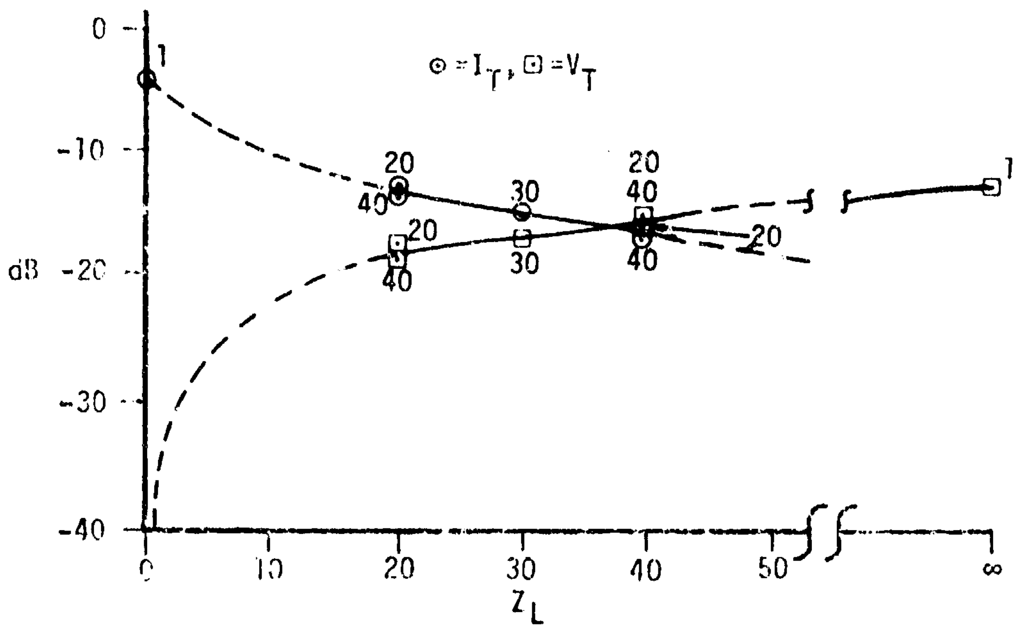


FIGURE 75 MODE 1 INPUT Δ TRANS. TF1010
SHIELD ON OUTPUT Y PULSE P5

TABLE 27 TRANSFORMER TF1010

MODE: 2 SHIELD: ON
INPUT: COM. Y OUTPUT: COM. A
COMPUTER RUN: A0001651 DATA: INVERSE SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-7.23	-120.01	-53.58	P4
2A	0	.001	-95.17	-7.57	-44.73	
3A	30	30	-20.85	-16.24	-9.23	
4A						
5A						
6A						
7A						
8A						
1B	0	10^7	-5.97	-118.30	-52.66	P5
2B	0	.001	-94.58	-7.20	-43.15	
3B	30	30	-15.03	-15.76	-0.97	
4B						
5B						
6B						
7B						
8B						

TABLE 28 TRANSFORMER TF1010

MODE: 2 SHIELD: ON
INPUT: COM. Δ OUTPUT: COM. Y
COMPUTER RUN: ARED3018 DATA: INVERSE SHAKER

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	0	10^7	-11.27	-120.28	-61.11	P4
2A	0	.001	-94.50	-3.37	-44.17	
3A	30	30	-20.21	-11.54	-9.95	
4A						
5A						
6A						
7A						
8A						
1B	0	10^7	-10.61	-121.00	-61.03	P5
2B	0	.001	-94.53	-4.10	-43.49	
3B	30	30	-14.92	-12.58	-8.09	
4B						
5B						
6B						
7B						
8B						

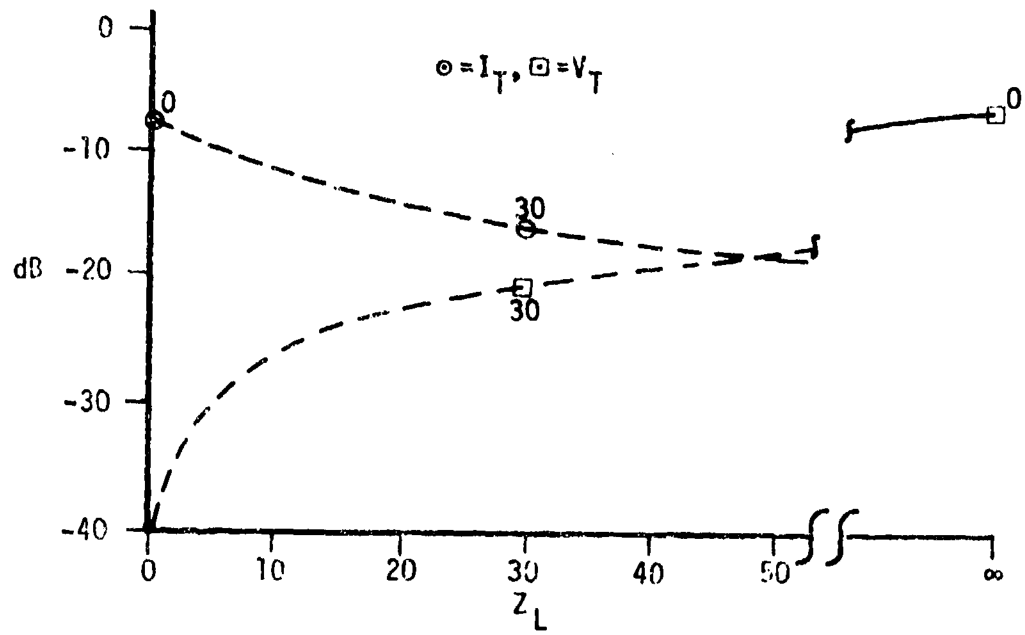


FIGURE 76 MODE 2 INPUT Y TRANS. TF1010
SHIELD ON OUTPUT Δ PULSE P4

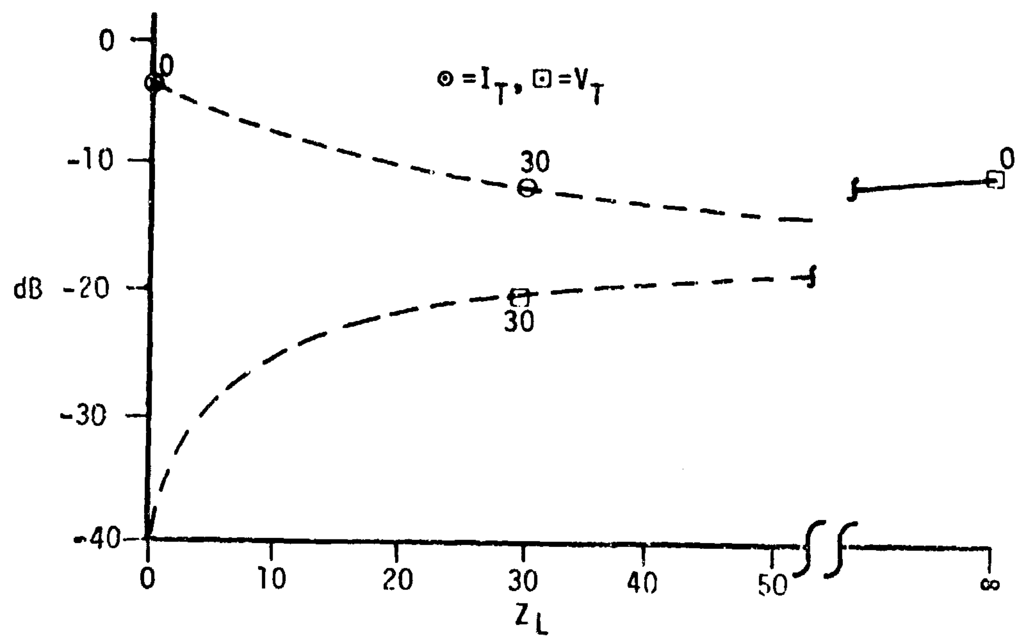


FIGURE 77 MODE 2 INPUT Δ TRANS. TF1010
SHIELD ON OUTPUT Y PULSE P4

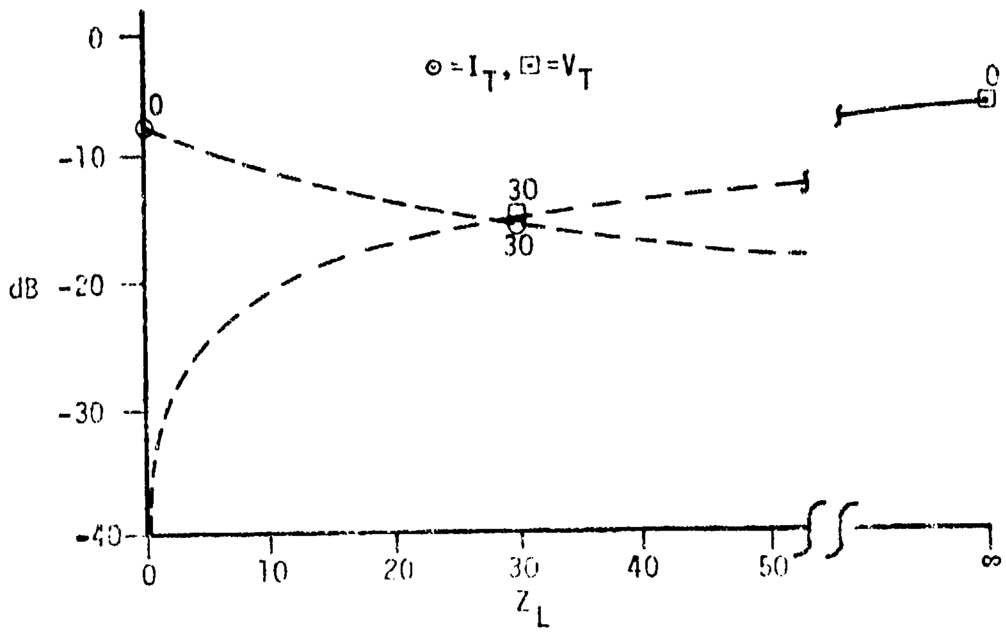


FIGURE 78	MODE 2	INPUT	Y	TRANS.	TF1010
	SHIELD ON	OUTPUT	Δ	PULSE	P5

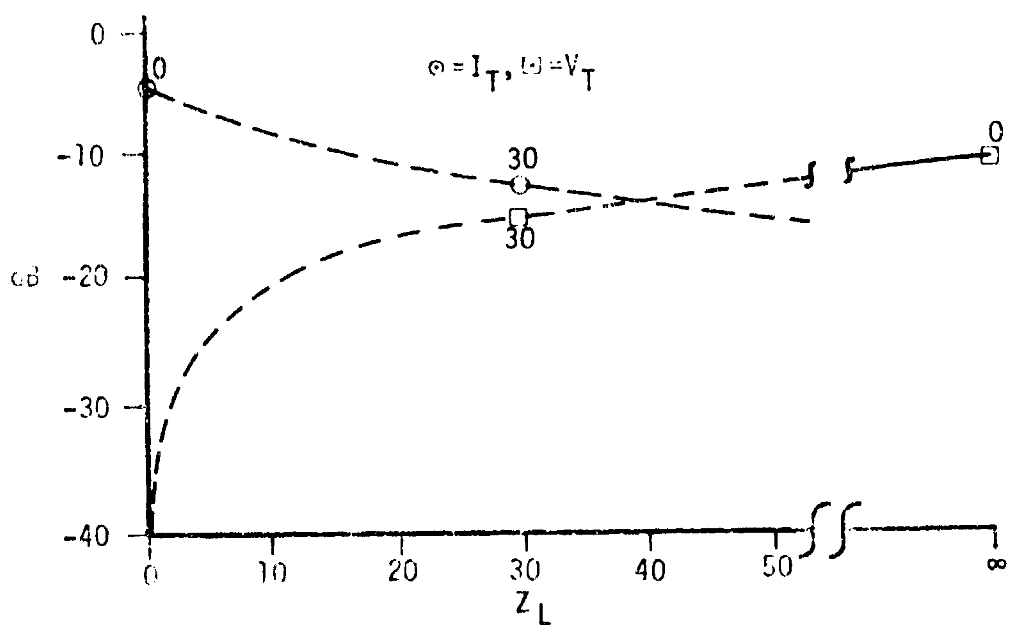


FIGURE 79	MODE 2	INPUT	Δ	TRANS.	TF1010
	SHIELD ON	OUTPUT	Y	PULSE	P5

TABLE 29 TRANSFORMER TF1010

MODE: 5 SHIELD: ON
INPUT: DIF. Y OUTPUT: DIF. Δ
COMPUTER RUN: F0003427 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-0.35	-121.03	-54.97	P4
2A	1	.001	-109.26	-29.70	-67.63	
3A	30	30	-22.90	-18.59	-4.38	
4A						
5A						
6A						
7A						
8A						
1B	1	10^7	-14.24	-125.26	-49.65	P5
2B	1	.001	-120.39	-31.32	-64.65	
3B	30	30	-31.77	-29.52	-12.88	
4B						
5B						
6B						
7B						
8B						

TABLE 30 TRANSFORMER TF1010

MODE: 5
INPUT: DIF. [illegible]
COMPUTER RUN: *ARED5067
F0003426

SHIELD: ON
OUTPUT: DIF. Y
DATA: *INVERSE SHAKER TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-2.93	-123.29	-61.03	P4
2A	1	.001	-109.92	-29.25	-67.75	
3A	30	30	-23.01	-17.73	-5.96	
4A						
5A						
6A						
7A						
8A						
1B	1	10^7	-14.94	-124.46	-53.04	P5
2B	1	.001	-120.25	-29.70	-65.03	
3B	30	30	-30.46	-28.38	-13.35	
4B*	30	2.5	-54.50	-26.60	-33.86	
5B*	30	5	-48.62	-26.58	-30.09	
6B*	30	10	-42.55	-26.80	-25.79	
7B*	30	50	-27.98	-23.69	-12.65	
8B*	30	.001	-121.79	-26.09	-68.60	
9B*	30	30	-31.90	-23.91	-17.25	

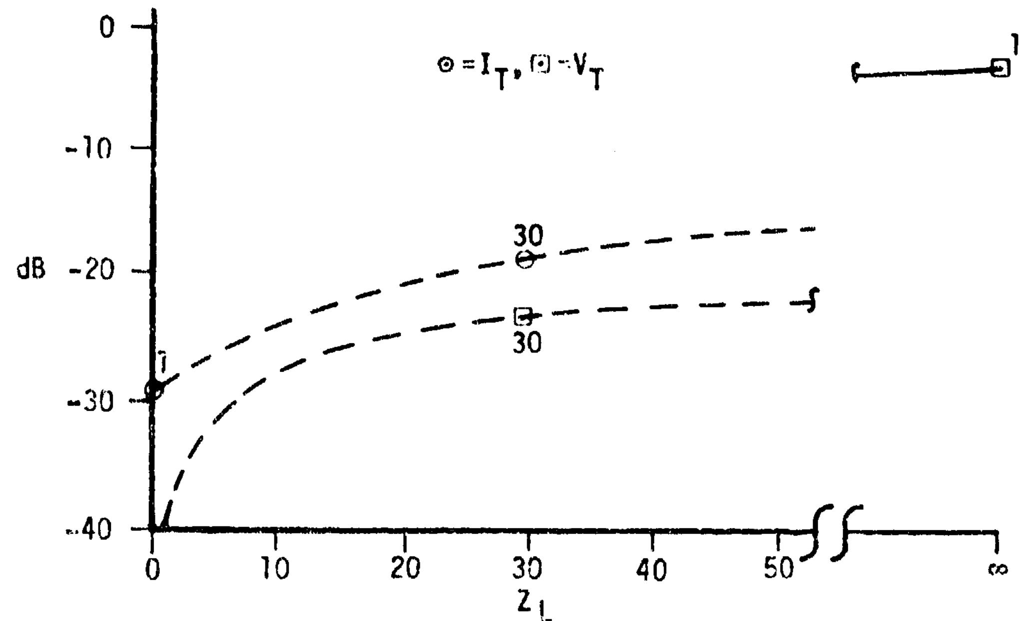


FIGURE 80	MODE	5	INPUT	Y	TRANS.	TF 1010
	SHIELD	ON	OUTPUT	Δ	PULSE	P4

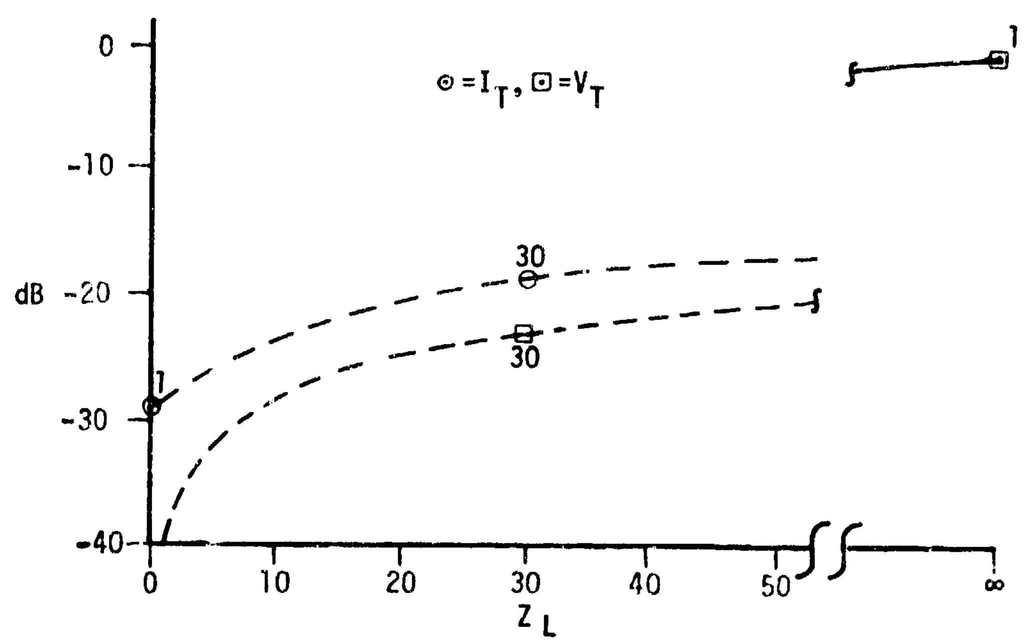


FIGURE 81	MODE	5	INPUT	Δ	TRANS.	TF1010
	SHIELD	ON	OUTPUT	Y	PULSE	P4

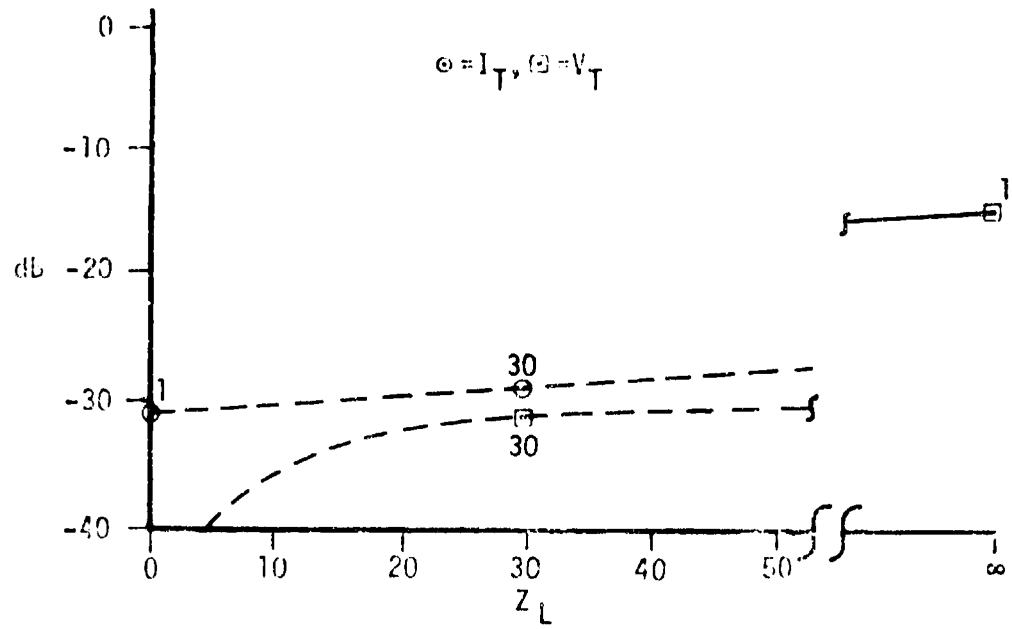


FIGURE 82 MODE 5 INPUT Y TRANS. TF1010
SHIELD ON OUTPUT Δ PULSE P5

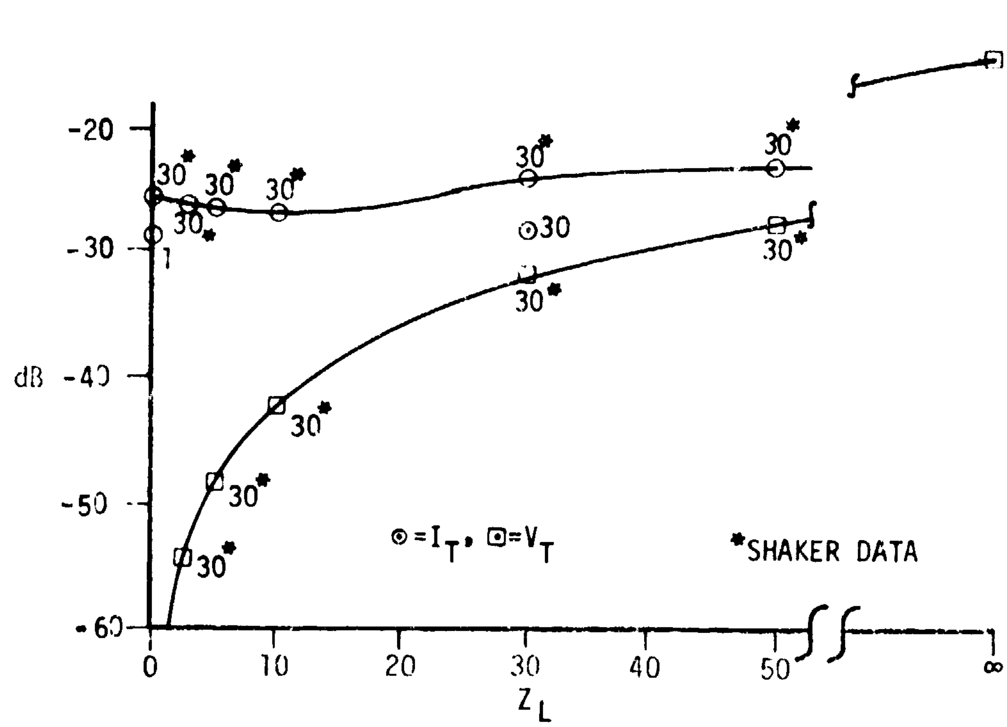


FIGURE 83 MODE 5 INPUT Δ TRANS. TF1010
SHIELD ON OUTPUT Y PULSE P5

TABLE 31 TRANSFORMER CONTROL

MODE: 1A
INPUT: COM. 480V
COMPUTER RUN: FC003392
F0003432

SHIELD:
OUTPUT: DIF. 120V
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-5.88	-106.83	-45.08	P4
2A	1	.001	-108.68	-10.28	-54.85	
3A	30	5	-35.77	-10.05	-18.74	
4A	30	15	-26.50	-10.30	-14.41	
5A	30	30	-21.04	-10.84	-12.07	
6A	30	10^7	-6.60	-106.63	-44.88	
7A	30	.001	-109.66	-9.98	-55.51	
8A						
1B	1	10^7	-5.32	-107.72	-41.31	P5
2B	1	.001	-108.59	-11.10	-49.70	
3B	30	5	-34.76	-10.24	-13.56	
4B	30	15	-25.54	-10.53	-9.42	
5B	30	30	-19.65	-10.63	-7.31	
6B	30	10^7	-5.12	-106.57	-41.05	
7B	30	.001	-108.47	-9.98	-50.24	
8B	30	10^4	-5.13	-46.59	-11.95	
9B	30	10^3	-5.63	-27.17	-6.27	
10B	30	10^2	-11.30	-12.69	-5.31	
11B	1	10^4	-5.37	-47.77	-12.19	
12B	1	10^2	-12.54	-14.90	-4.90	

TABLE 32 TRANSFORMER CONTROL

MODE: 2A
SHIELD:
INPUT: DIF. 480V
OUTPUT: DIF. 120V
COMPUTER RUN: F0003393
F0003433
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-2.91	-121.45	-69.10	P4
2A	1	.001	-107.54	-26.31	-72.98	
3A	50	5	-35.86	-7.03	-18.87	
4A	50	15	-26.49	-7.12	-14.32	
5A	50	30	-20.56	-7.11	-11.95	
6A	50	10^7	-2.87	-98.92	-51.73	
7A	50	.001	-109.86	-7.09	-55.87	
8A						
1B	1	10^7	-3.79	-105.98	-52.63	P5
2B	1	.001	-106.65	-9.32	-60.55	
3B	50	5	-31.41	-2.06	-11.99	
4B	50	15	-22.16	-2.00	-7.69	
5B	50	30	-16.92	-2.29	-5.36	
6B	50	10^7	-3.02	-98.06	-38.54	
7B	50	.001	-105.34	-2.17	-48.74	
8B	50	10^4	-3.05	-38.10	-9.35	
9B	50	10^3	-3.79	-18.92	-3.31	
10B	50	10^2	-10.61	-5.81	-2.70	
11B	1	10^2	-10.51	-12.78	-14.13	
12B	1	10^4	-3.84	-46.03	-23.15	

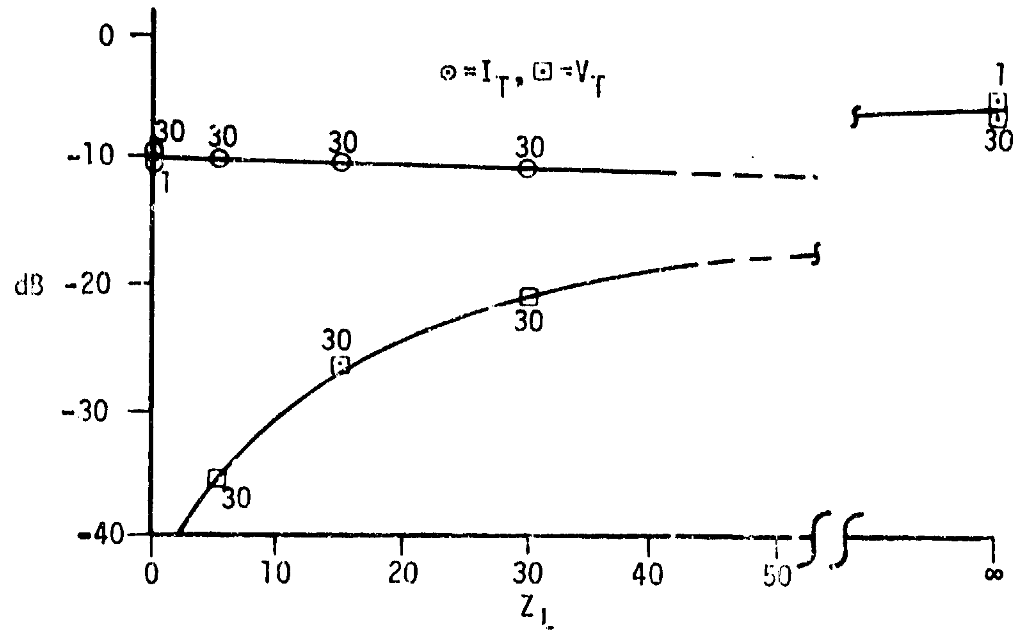


FIGURE 84 MODE 1A INPUT COM. 480V TRANS. CONTROL
SHIELD OUTPUT DIFF 120V PULSE P4

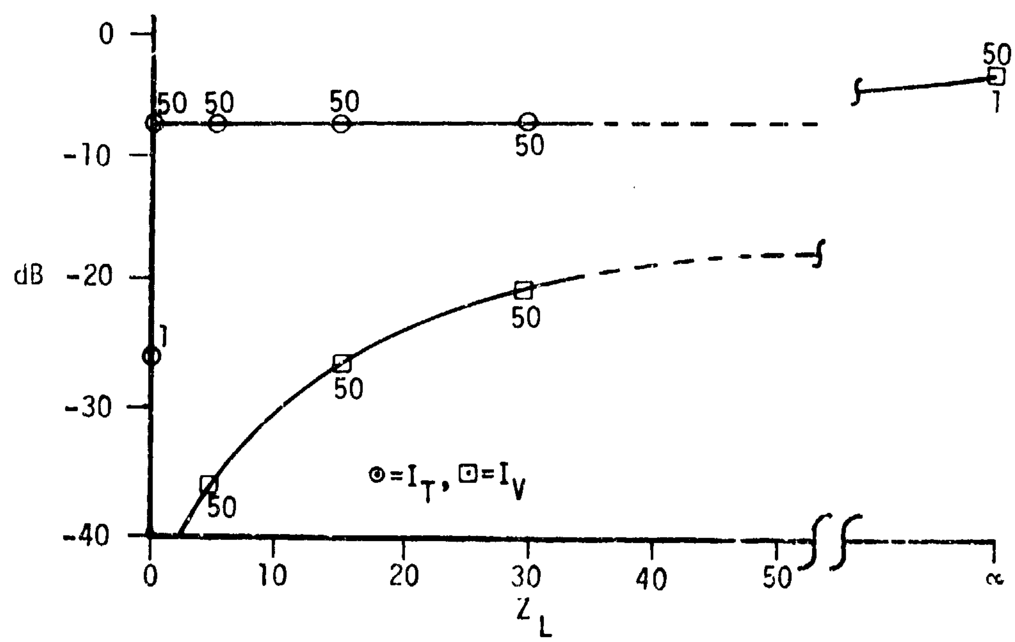


FIGURE 85 MODE 2A INPUT DIFF 480V TRANS. CONTROL
SHIELD OUTPUT COM. 120V PULSE P4

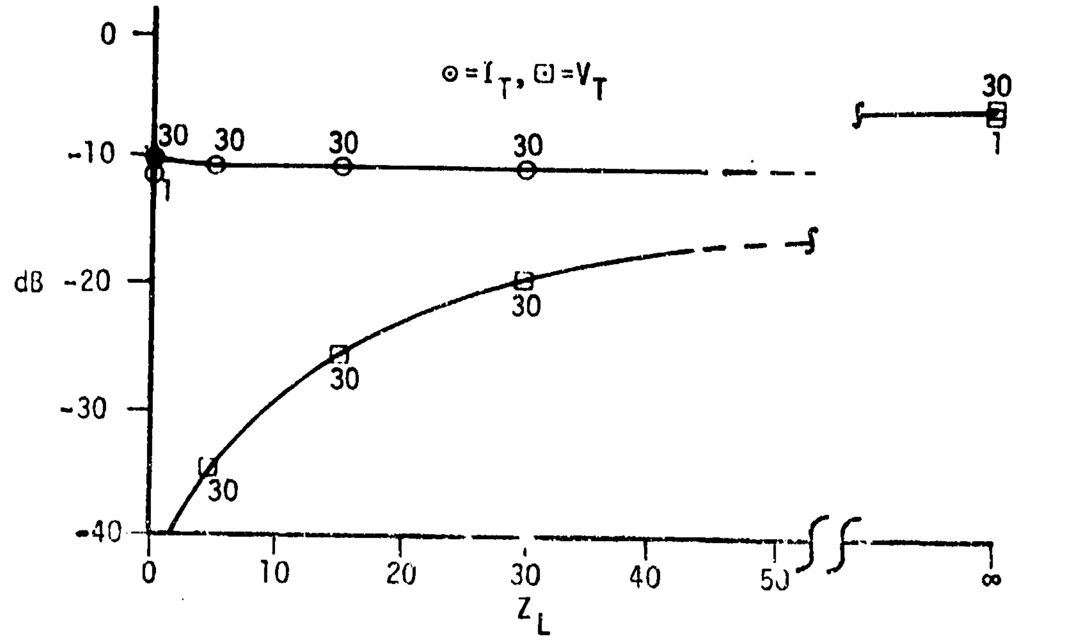


FIGURE 86 MODE 1A INPUT COM 480V TRANS. CONTROL
SHIELD OUTPUT DIFF 120V PULSE P5

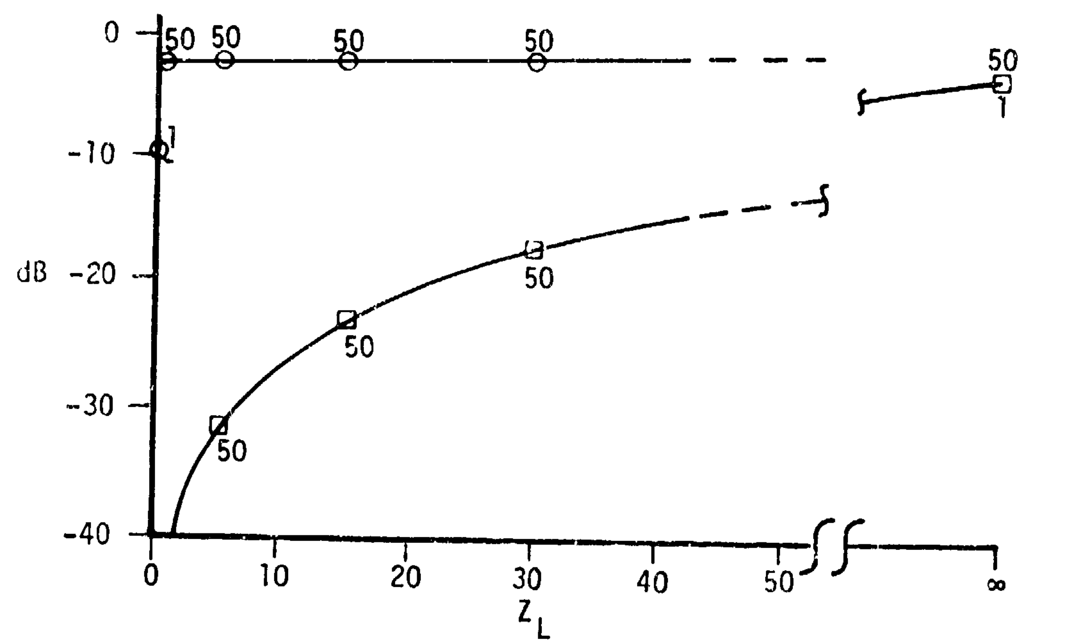


FIGURE 87 MODE 2A INPUT DIFF 480V TRANS. CONTROL
SHIELD OUTPUT DIFF 120V PULSE P5

TABLE 33 TRANSFORMER T17363

MODE: 3A SHIELD:
INPUT: COM. LV WINDING OUTPUT: COM. HV WINDING
COMPUTER RUN: F0003423 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	+4.12	-112.91	-39.54	P4
2A	1	.001	-87.73	-4.50	-41.32	
3A	10	50	-2.86	-10.12	-1.33	
4A	25	50	-3.54	-8.64	-0.76	
5A	50	50	-7.25	-8.90	-0.74	
6A	25	10	-13.00	-4.10	-4.59	
7A						
8A						
1B	1	10^7	+2.72	-113.56	-47.29	P5
2B	1	.001	-90.22	-5.51	-40.67	
3B	10	50	-3.42	-11.59	-0.99	
4B	25	50	-3.80	-10.64	+1.05	
5B	50	50	-6.08	-12.03	+2.15	
6B	25	10	-12.70	-5.68	-3.75	
7B						
8B						
1C	1	10^7	-3.50	-116.14	-52.01	P1
2C	1	.001	-98.40	-9.93	-44.60	
3C	10	50	-11.81	-16.49	-4.88	
4C	25	50	-12.72	-16.61	-3.87	
5C	50	50	-15.40	-18.96	-3.68	
6C	25	10	-22.74	-12.50	-7.27	

TABLE 34 TRNASFORMER T17363

MODE: 3A SHIELD:
INPUT: COM. HV WINDING OUTPUT: COM. LV WINDING
COMPUTER RUN: F0003422 DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
1A	1	10^7	-0.74	-107.73	-43.44	P4
2A	1	.001	-87.88	+2.83	-40.50	
3A	50	10	-13.89	+1.44	-4.84	
4A	50	25	-8.68	-1.09	-2.40	
5A	50	50	-7.87	-6.17	-0.86	
6A	10	25	-6.45	-1.56	-2.76	
7A						
8A						
1B	1	10^7	-3.93	-108.79	-50.27	P5
2B	1	.001	-90.27	+3.96	-39.03	
3B	50	10	-16.27	+0.51	-3.84	
4B	50	25	-11.56	-2.66	-1.20	
5B	50	50	-10.85	-8.67	+2.48	
6B	10	25	-9.75	-2.12	-2.42	
7B						
8B						
1C	1	10^7	-14.36	-115.9[illegible]	-53.39	P1
2C	1	.001	-98.19	+0.78	-38.88	
3C	50	10	-24.42	-5.59	-6.15	
4C	50	25	-19.83	-8.95	-4.54	
5C	50	50	-19.29	-14.88	-3.53	
6C	10	25	-18.68	-8.89	-4.25	

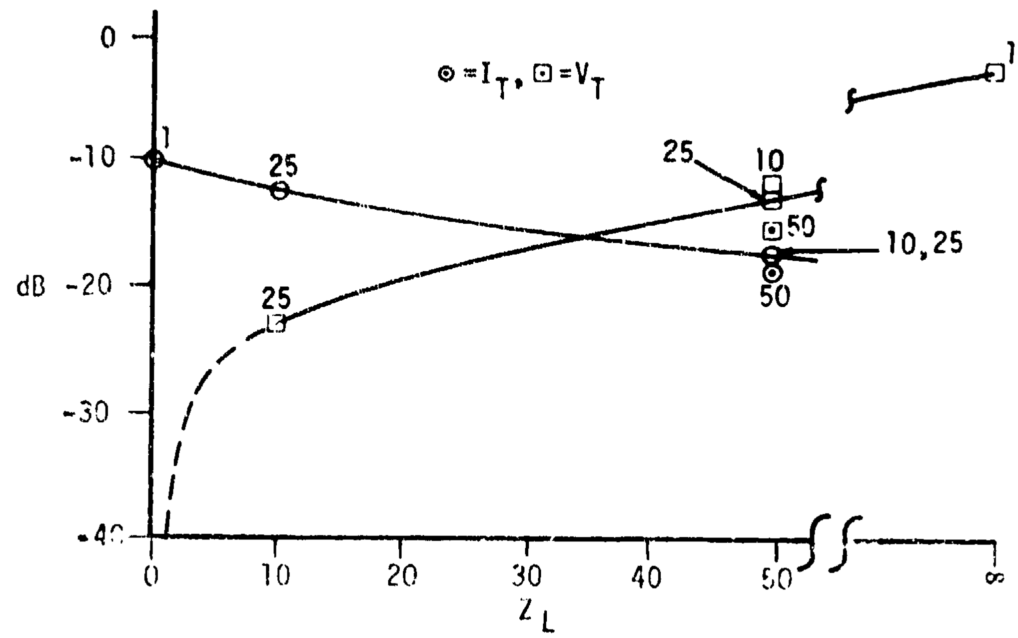


FIGURE 88 MODE 3A INPUT LV TRANS. TF17363
SHIELD OUTPUT HV PULSE P1

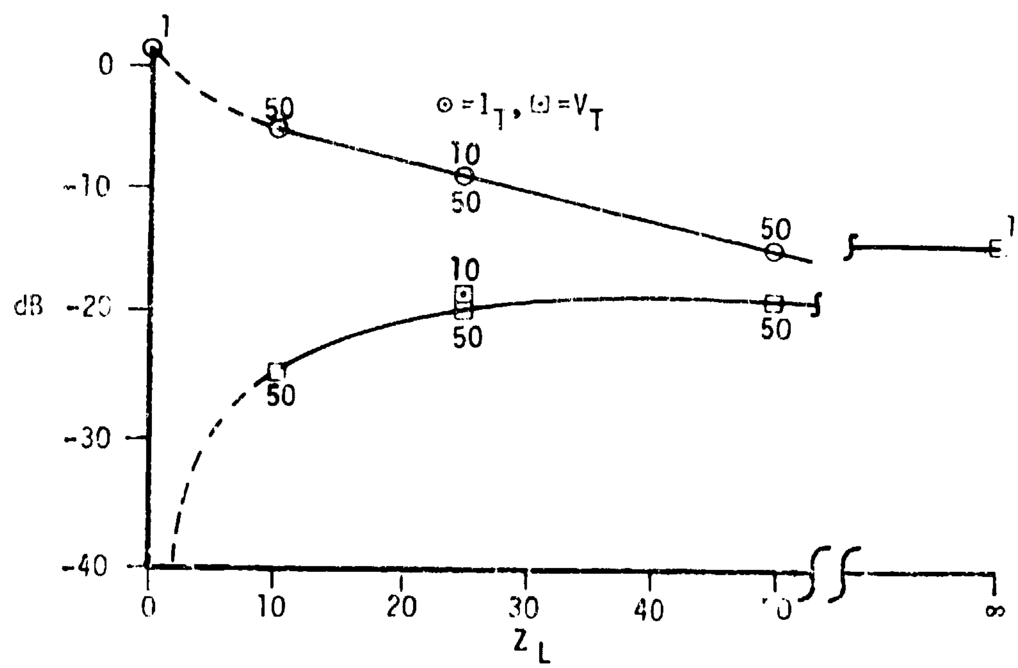


FIGURE 89 MODE 3A INPUT HV TRANS. TF17363
SHIELD OUTPUT LV PULSE P1

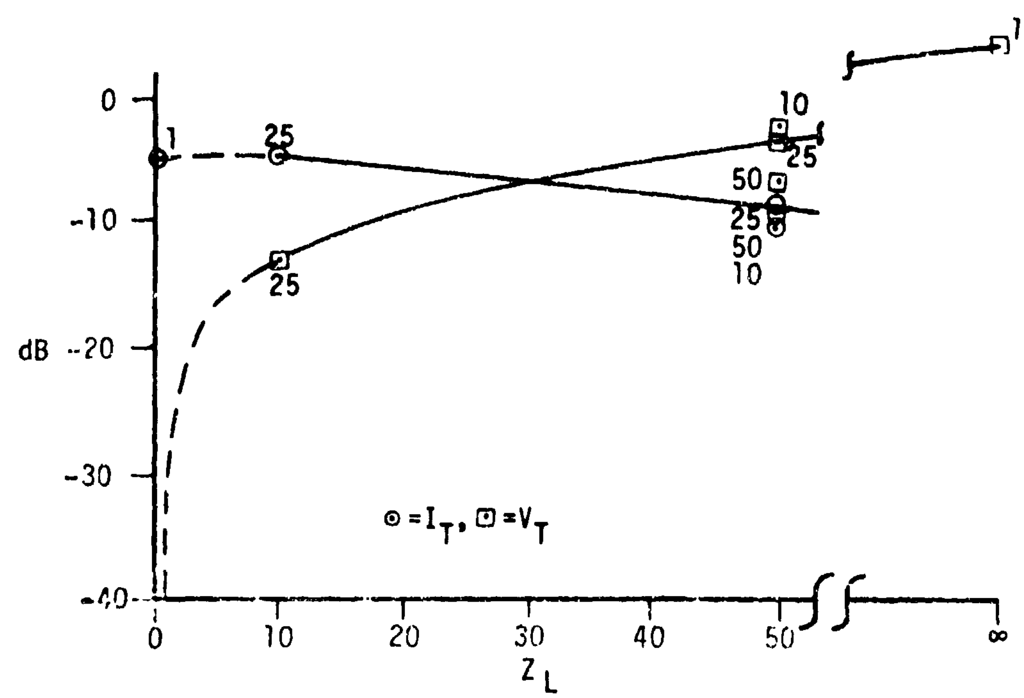


FIGURE 90 MODE 3A INPUT LV TRANS. TF17363
SHIELD OUTPUT HV PULSE P4

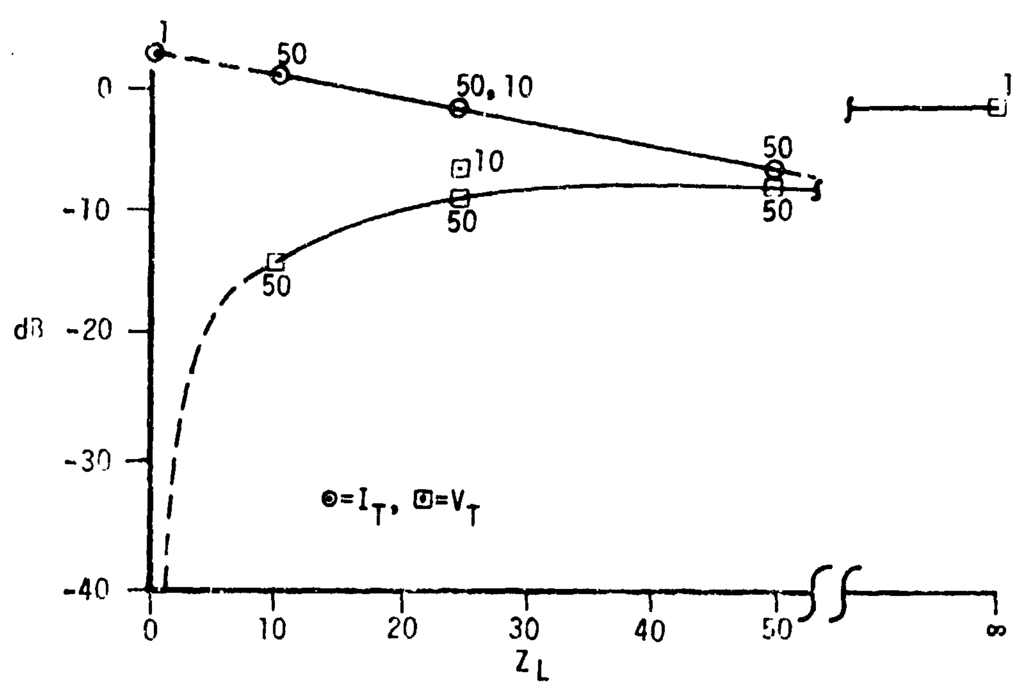


FIGURE 91 MODE 3A INPUT HV TRANS. TF17363
SHIELD OUTPUT LV PULSE P4

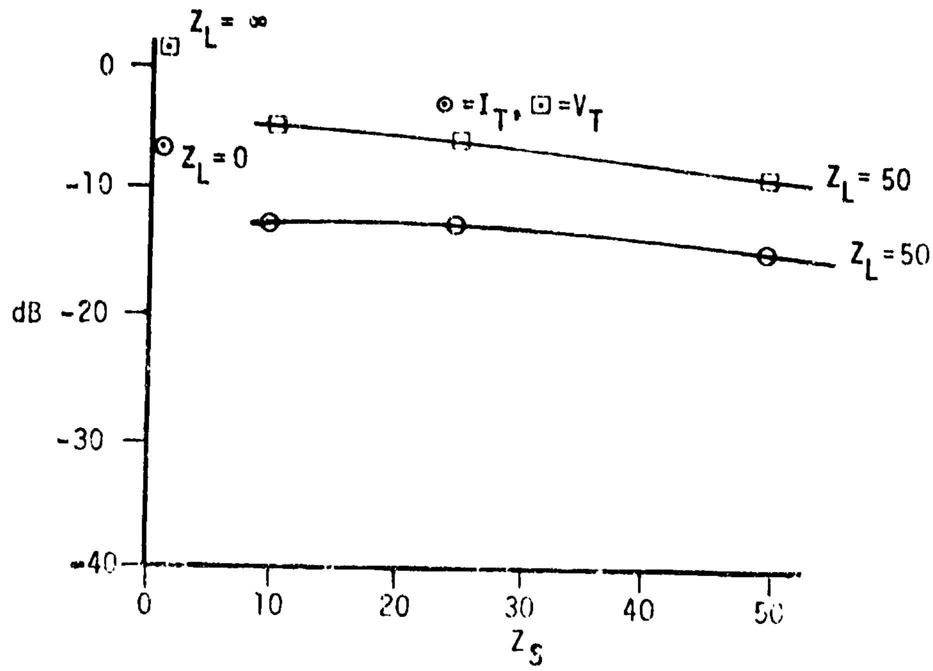


FIGURE 92 MODE 3A INPUT LV TRANS. TF17363
SHIELD OUTPUT HV PULSE P5

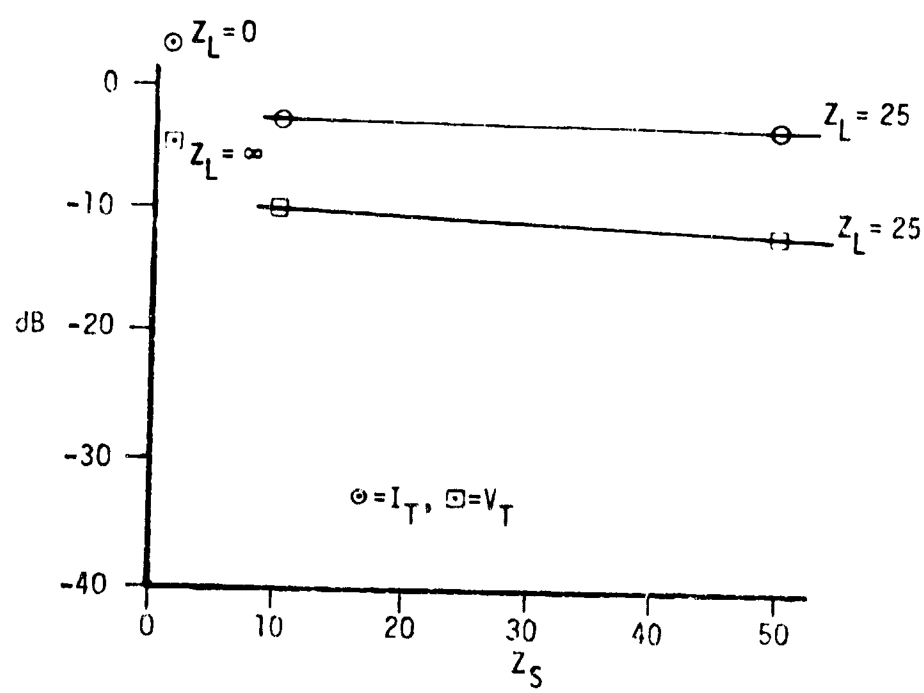


FIGURE 93 MODE 3A INPUT HV TRANS. TF17363
SHIELD OUTPUT LV PULSE P5

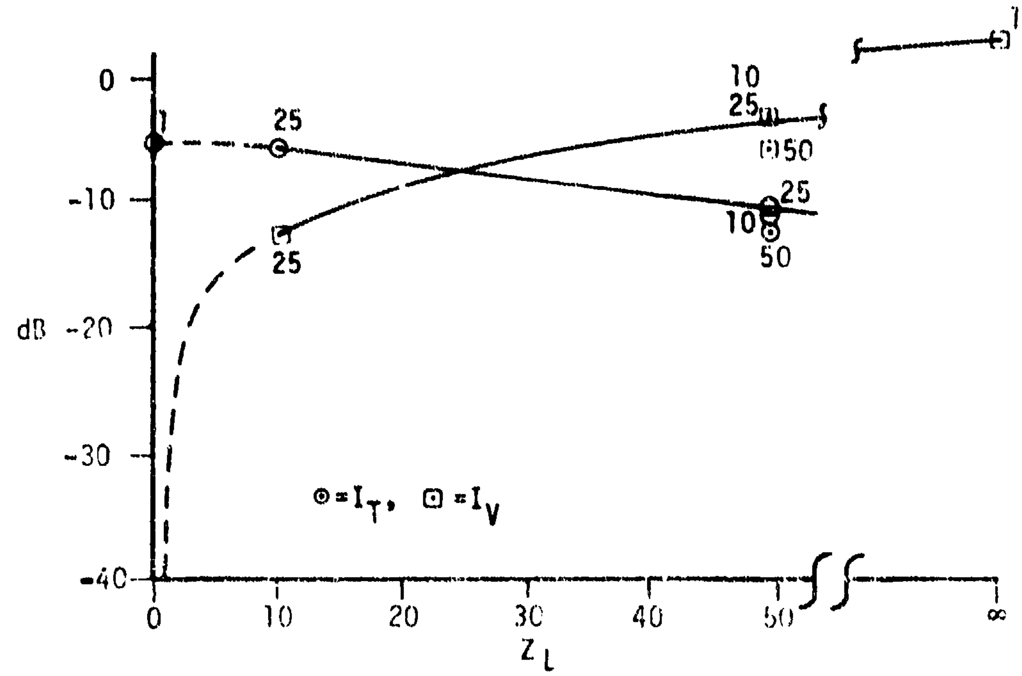


FIGURE 94 MODE 3A INPUT LV TRANS. TF17363
SHIELD OUTPUT HV PULSE P5

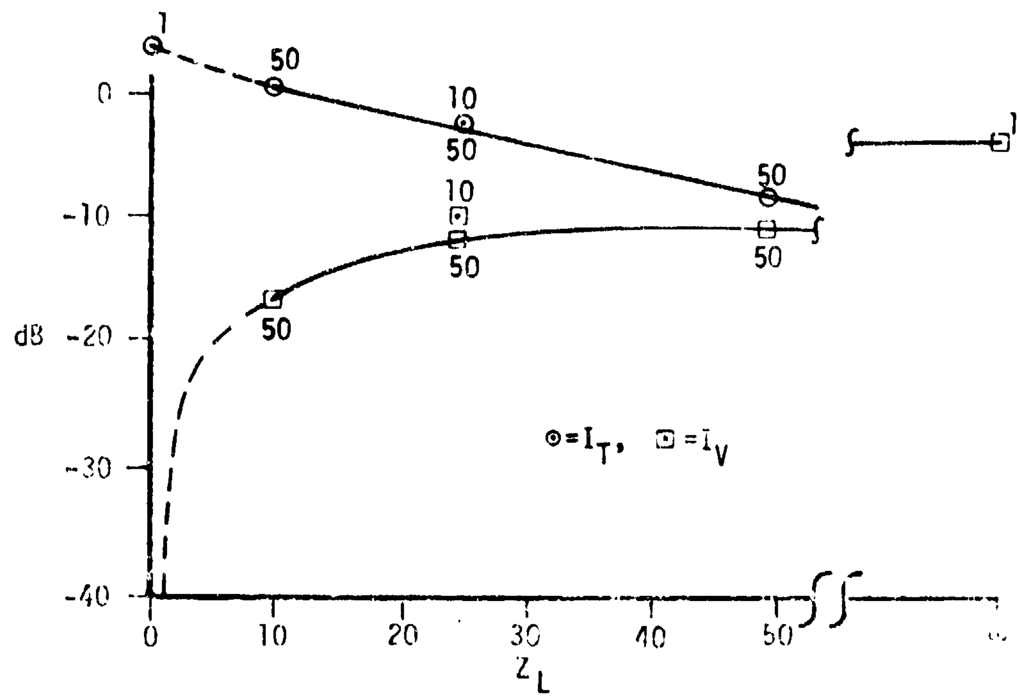


FIGURE 95 MODE 3A INPUT HV TRANS. TF17363
SHIELD OUTPUT LV PULSE P5

TABLE 35 REGULATOR

MODE: 4A BOOST **SHIELD:**
INPUT: 1 **OUTPUT:** 2
COMPUTER RUN: FBLU6080, FRED7035 **DATA:** TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3A	1	10^7	3.28	119.53	-58.60	P4
4A	50	10^7	2.71	97.75	-45.13	
5A	10	10	-14.53	-4.77	2.36	
6A	10	50	-5.32	-10.22	-2.63	
7A	1	50	-4.18	-21.05	8.13	
8A	100	50	-6.66	-3.41	-0.61	
9A	50	3	27.98	-2.42	-4.69	
10A	50	10	-18.11	-3.11	-2.49	
11A	50	20	-12.79	-3.88	-1.74	
12A	50	50	-6.51	-5.41	-0.91	
13A	50	100	-2.91	-7.20	[illegible]	
14A	100	10	-18.81	-2.06	2.87	
17A	1	1	-26.58	-9.44	-3.81	
18A	50	1	-37.17	-2.03	-7.79	

NOTE: CASE 1A, 2A, 15A and 16A are void.

TABLE 35 (Cont.) REGULATOR

MODE: 4A BOOST　　**SHIELD:**
INPUT: 1　　**OUTPUT:** 2
COMPUTER RUN: FBLU6081, FBLU6101, FRED7035　　**DATA:** TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3B	1	10^7	-2.34	-114.05	-49.52	P5
4B	50	10^7	0.65	-106.15	-37.33	
5B	10	10	-22.47	-13.16	-4.94	
6B	10	50	-11.23	-15.65	-3.14	
7B	1	50	-12.60	-18.64	-5.10	
8B	100	50	-10.02	-10.55	-2.70	
9B	50	3	-32.24	10.39	-10.14	
10B	50	10	-22.18	-10.75	-6.[illegible]	
11B	50	20	-16.70	-11.19	-4.31	
12B	50	50	-10.23	-12.37	-2.70	
13B	50	100	-6.30	-14.12	-1.97	
14B	100	10	-22.03	-9.08	-6.71	
17B	1	1.[illegible]	40.99	12.96	-6.74	
18B	50	1	-41.61	-10.24	-14.45	

NOTE: CASE 1B, 2B, 15B and 16B are void.

TABLE 36 REGULATOR

MODE: 4A BOOST
SHIELD:
INPUT: 2
OUTPUT: 1
COMPUTER RUN: FBLU6082, FRED7033
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3A	1	10^7	1.41	-118.96	-60.39	#4
4A	50	10^7	1.21	-97.91	-44.27	
5A	10	10	-14.85	-3.08	-2.22	
6A	10	50	-6.47	-8.73	-3.14	
7A	1	50	-5.64	-19.96	-9.79	
8A	100	50	-8.10	-0.99	-0.07	
9A	50	3	-27.86	-0.62	-3.38	
10A	50	10	-18.24	-0.80	-1.79	
11A	50	20	-13.15	-1.13	-1.28	
12A	50	50	-7.42	-3.15	-0.67	
13A	50	100	-4.12	5.35	0.07	
14A	100	10	-19.73	-0.16	-2.06	
17A	1	1	-26.83	-7.61	-5.37	
18A	50	1	-36.95	-0.35	-5.88	

NOTE: 1A, 2A, 15A, and 16A are void.

TABLE 36 (Cont.) REGULATOR

MODE: 4A BOOST
SHIELD:
INPUT: 2
OUTPUT: 1
COMPUTER RUN: FBLU6083, FRED7033
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3B	1	10^7	-4.97	-116.25	50.28	P5
4B	50	10^7	-3.18	-107.39	41.23	
5B	10	10	-23.57	12.42	-3.74	
6B	10	50	-12.88	-15.58	-2.6[illegible]	
7B	1	50	-13.50	-19.01	-5.37	
8B	100	50	-11.68	-9.21	-2.24	
9B	50	3	-33.65	-[illegible].62	-8.42	
10B	50	10	-23.77	-9.11	-4.81	
11B	50	20	-18.45	-9.71	-3.37	
12B	50	50	-12.35	-11.34	-2.18	
13B	50	100	-8.38	-13.67	-1.76	
14B	100	10	-23.34	-7.25	-5.52	
17B	1	1	-41.01	-12.45	-6.31	
18B	50	1	-42.95	-8.40	-12.52	

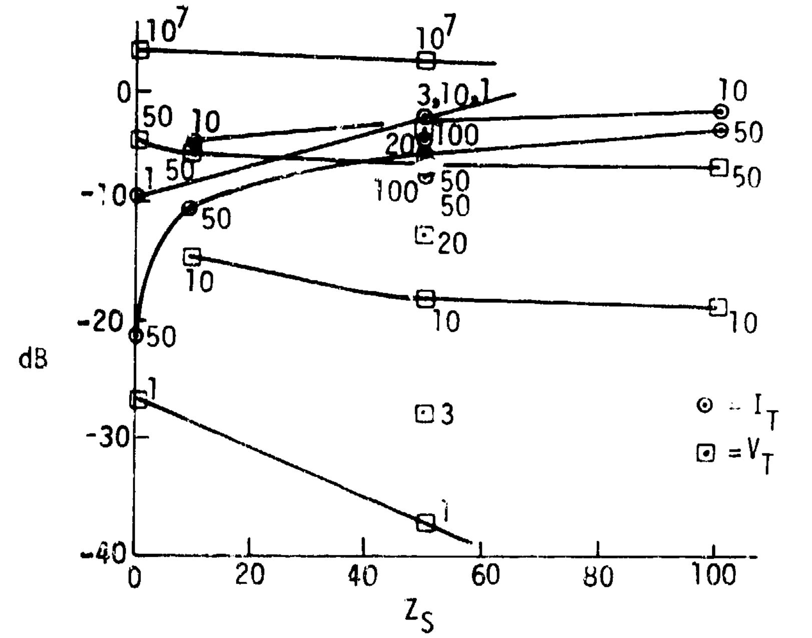


FIGURE 96 MODE 4A BOOST INPUT 1 OUTPUT 2 REGULATOR PULSE P4

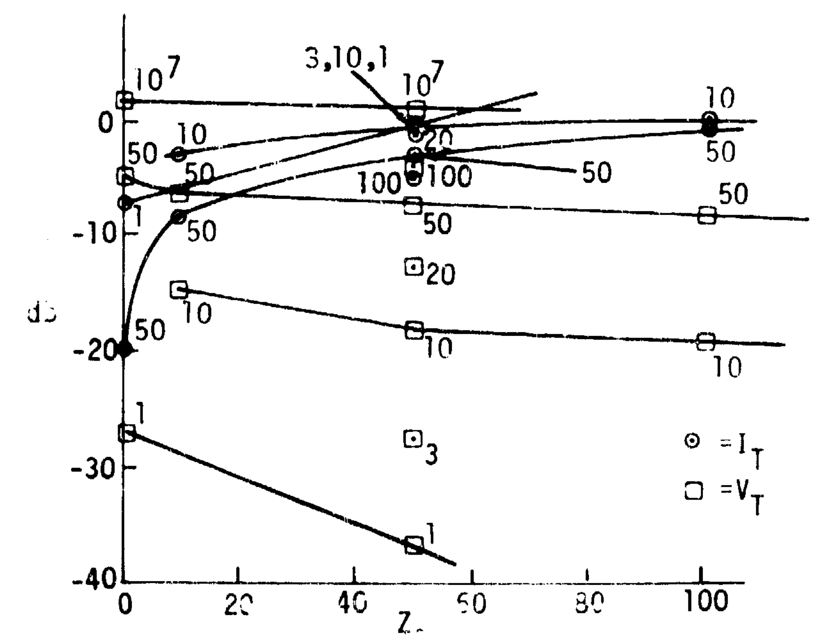


FIGURE 97 MODE 4A BOOST INPUT 2 OUTPUT 1 REGULATOR PULSE P4

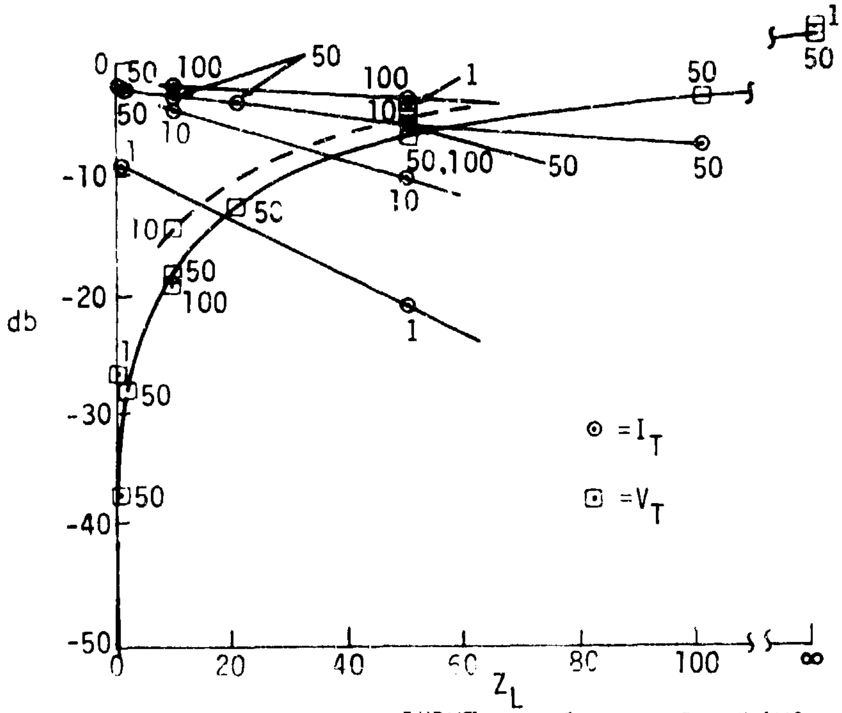


FIGURE 98 MODE 4A BOOST INPUT 1 REGULATOR
OUTPUT 2 PULSE P4

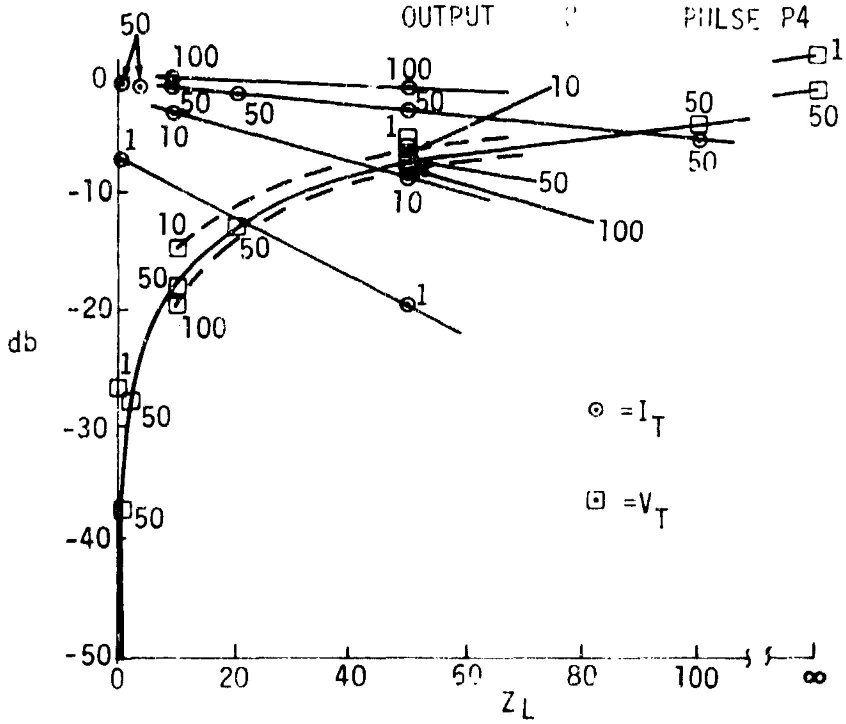


FIGURE 99 MODE 4A BOOST INPUT 2 REGULATOR
OUTPUT 1 PULSE P4

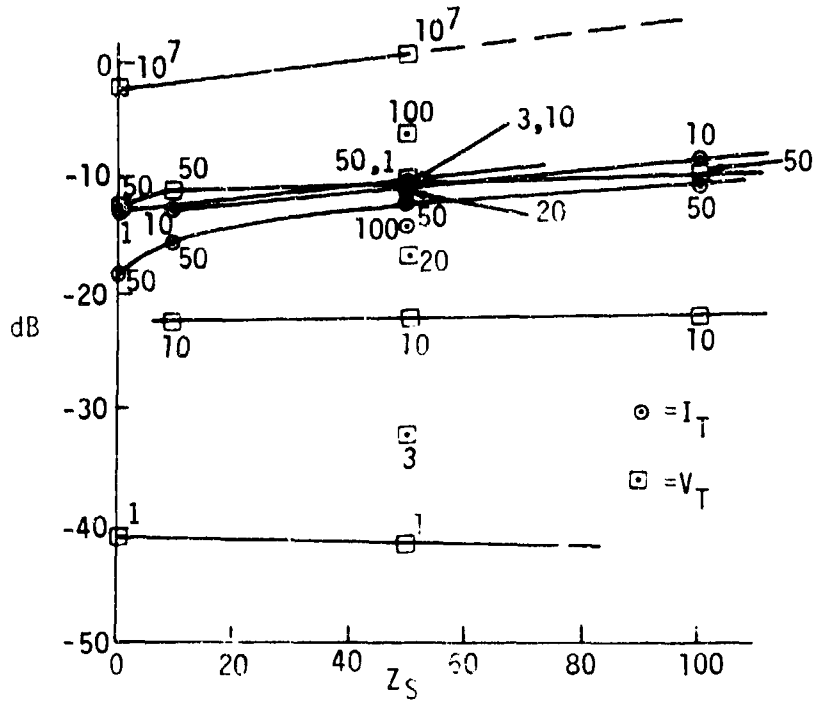


FIGURE 100 MODE 4A BOOST INPUT 1 REGULATOR
OUTPUT 2 PULSE P5

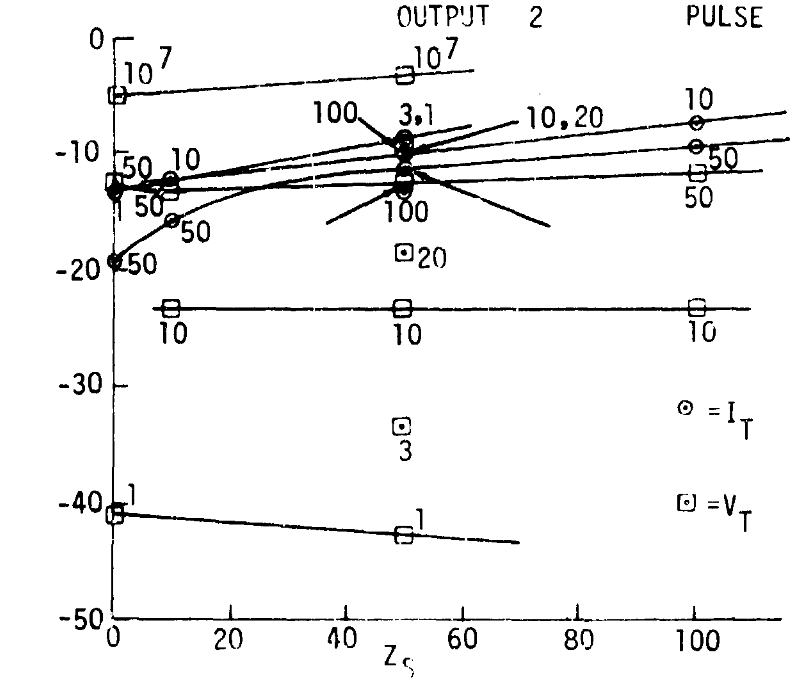


FIGURE 101 MODE 4A BOOST INPUT REGULATOR
OUTPUT 1 PULSE P5

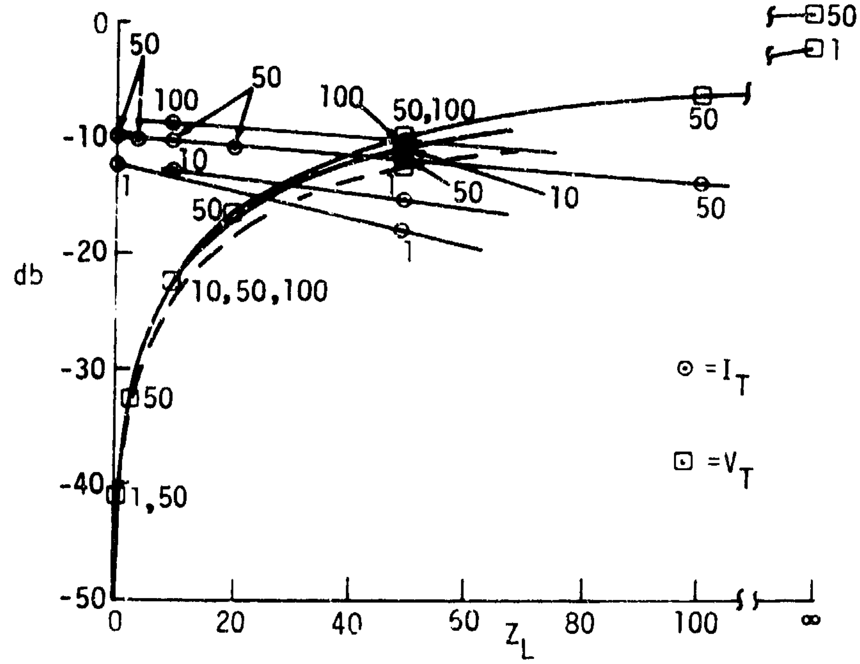


FIGURE 102 MODE 4A BOOST INPUT 1 OUTPUT 2 REGULATOR PULSE P5

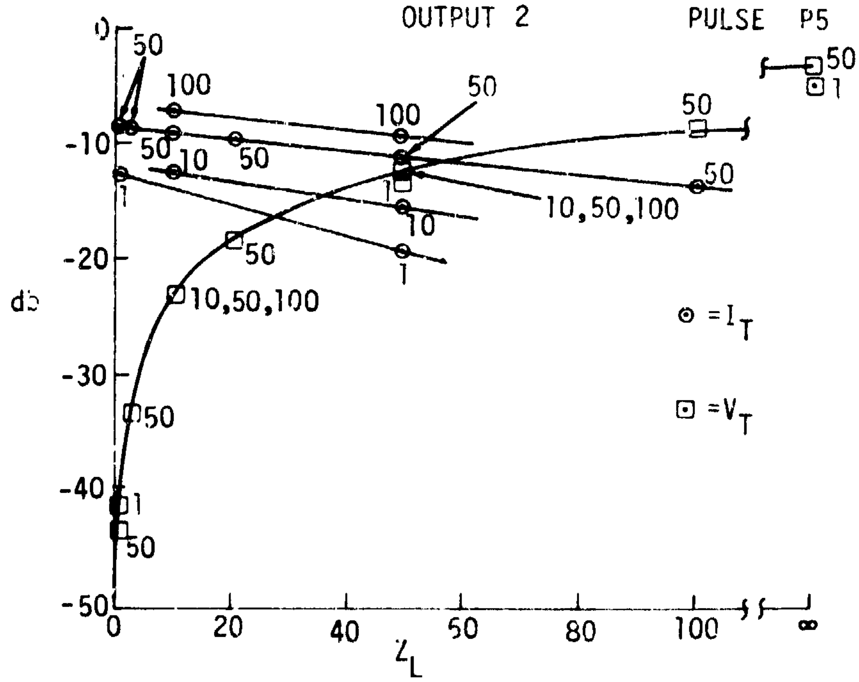


FIGURE 103 MODE 4A BOOST INPUT 2 OUTPUT 1 REGULATOR PULSE P5

TABLE 37 REGULATOR

MODE: 4A BUCK
SHIELD:
INPUT: 1
OUTPUT: 2
COMPUTER RUN: FBLU6084 · FRED7034
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3A	1	10^7	1.14	-118.90	61.60	#4
4A	50	10^7	1.58	-103.65	-47.09	
5A	10	10	-15.88	-6.18	3.59	
6A	10	50	-6.87	-12.14	-4.60	
7A	1	50	-6.33	-20.90	-11.25	
8A	100	50	-8.05	5.02	-2.15	
9A	50	3	-28.15	-2.07	-4.92	
10A	50	10	-18.51	-3.28	-2.99	
11A	50	20	-13.43	-4.58	2.56	
12A	50	50	-7.72	-7.33	-2.55	
13A	50	100	-4.50	-10.33	-3.01	
14A	100	10	-19.29	-1.96	3.21	
17A	1	1	-29.18	-7.66	-20.64	
18A	50	1	-37.53	-1.77	-[illegible].16	

NOTE: 1A, 2A, 15A, and 16A are void.

TABLE 37 (Cont.) REGULATOR

MODE: 4A BUCK
SHIELD:
INPUT: 1
OUTPUT: 2
COMPUTER RUN: FRED6096, FRED7034
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3B	1	10^7	-3.72	-114.47	-51.40	P5
4B	50	10^7	-0.41	-107.57	-43.66	
5B	10	10	-21.96	-12.48	-5.68	
6B	10	50	-12.75	-17.00	4.16	
7B	1	50	-13.15	-18.30	-6.71	
8B	100	50	11.28	-11.40	3.17	
9B	50	3	-23.20	-10.90	-9.93	
10B	50	10	-23.39	-11.52	-6.15	
11B	50	20	-18.00	-12.11	4.61	
12B	50	50	-11.61	-13.54	-3.37	
13B	50	100	-7.81	-15.40	-3.02	
14B	100	10	-22.95	9.45	6.58	
17B	1	1	43.78	14.95	-19.73	
18B	50	1	-42.31	10.48	-14.19	

NOTE: 1B, 2B, 15B, and 16B are void.

TABLE 38 REGULATOR

MODE: 4A BUCK | SHIELD:
INPUT: 2 | OUTPUT: 1
COMPUTER RUN: FRED6097, FRED7032 | DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3A	1	10^7	2.55	115.62	-58.59	P4
4A	50	10^7	3.37	-100.[illegible]7	-44.25	
5A	10	10	-16.31	5.40	-2.82	
6A	10	50	-6.55	-8.94	-3.50	
7A	1	50	-5.78	17.64	-9.13	
8A	100	50	-9.52	-3.76	-1.78	
9A	50	3	-29.66	-2.89	-4.76	
10A	50	10	-19.72	-3.09	-2.65	
11A	50	20	-14.48	-3.38	-2.12	
12A	50	50	8.36	5.13	-1.96	
13A	50	100	-4.4[illegible]	7.[illegible]3	[illegible]	
14A	100	10	-21.49	2.46	-3.09	
17A	1	1	2[illegible].42	-7.52	-2[illegible].11	
18A	50	1	-39.19	-2.97	-8.15	

NOTE: 1A, 2A, 15A, and 16A are void.

TABLE 38 (Cont.) REGULATOR

MODE: 4A BUCK
SHIELD:
INPUT: 2
OUTPUT: 1
COMPUTER RUN: FRED6098, FRED7030, FRED7032
DATA: TAPE

CASE	Z_S	Z_L	V_T	I_T	E_T	PULSE
3B	1	10^7	-4.21	-114.38	-49.20	P5
4B	50	10^7	-2.59	107.10	-43.58	
5B	10	10	-23.09	-11.45	-4.47	
6B	10	50	-13.77	-16.08	-2.97	
7B	1	50	-13.89	18.36	-5.28	
8B	100	50	-13.05	-10.55	-3.27	
9B	50	3	-34.56	-9.17	9.37	
10B	50	10	-25.44	-10.44	-5.94	
11B	50	20	-20.02	-10.97	-4.30	
12B	50	50	-13.69	-12.48	-2.97	
13B	50	100	-9.81	14.5[illegible]	-2.59	
14B	100	10	-24.84	-8.61	-6.94	
17B	1	1	-43.82	-13.95	-18.43	
18B	50	1	-43.69	-8.78	-14.21	

NOTE: 1B, 2B, 15B, and 16B are void.

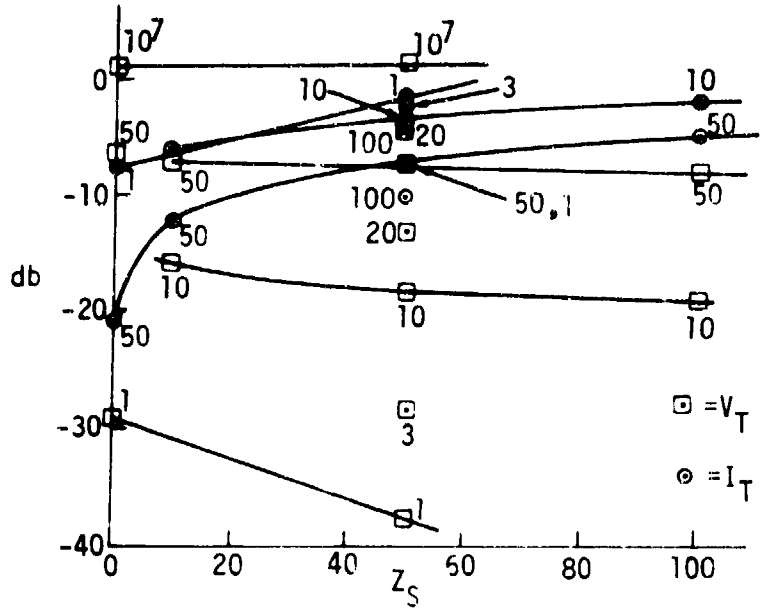


FIGURE 104 MODE 4A BUCK INPUT 1 REGULATOR
OUTPUT 2 PULSE P4

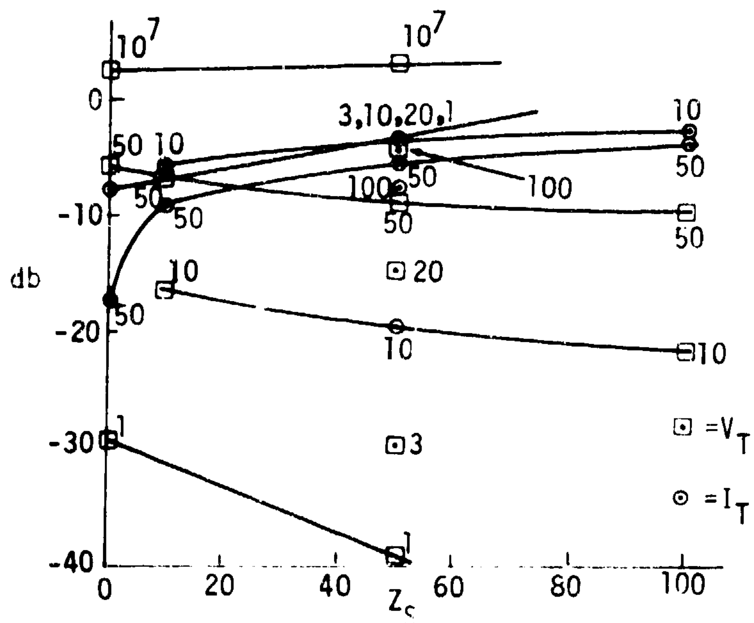


FIGURE 105 MODE 4A BUCK INPUT 2 REGULATOR
OUTPUT 1 PULSE P4

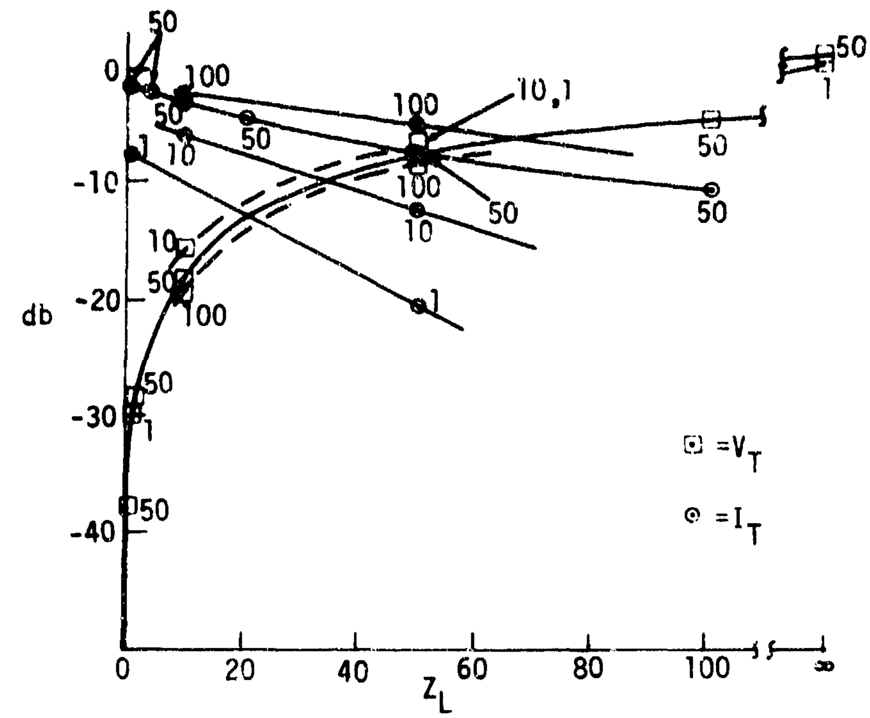


FIGURE 106 MODE 4A BUCK INPUT 1 OUTPUT 2 REGULATOR PULSE P4

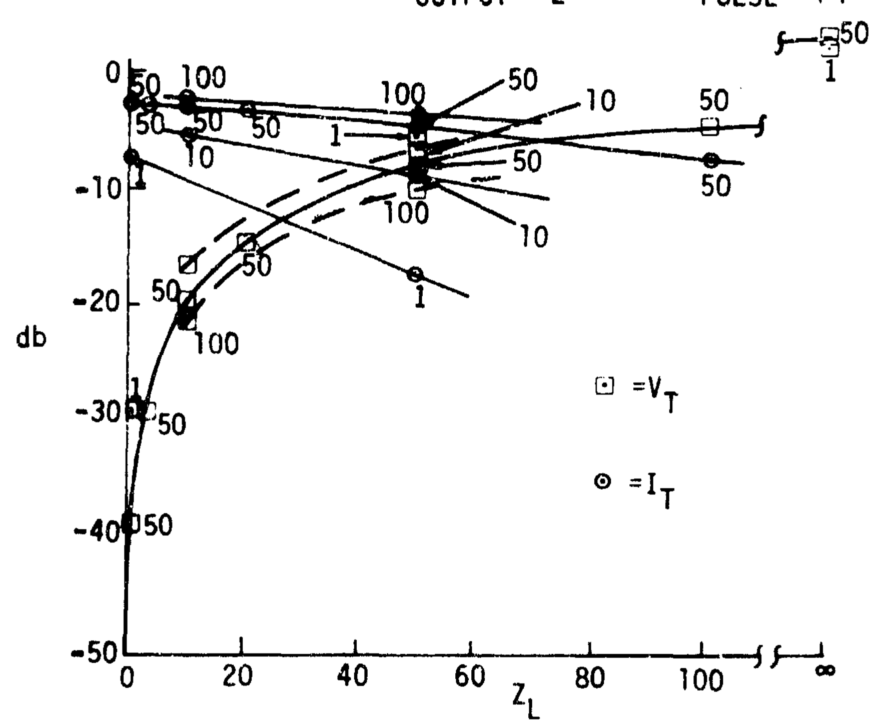


FIGURE 107 MODE 4A BUCK INPUT 2 OUTPUT 1 REGULATOR PULSE P4

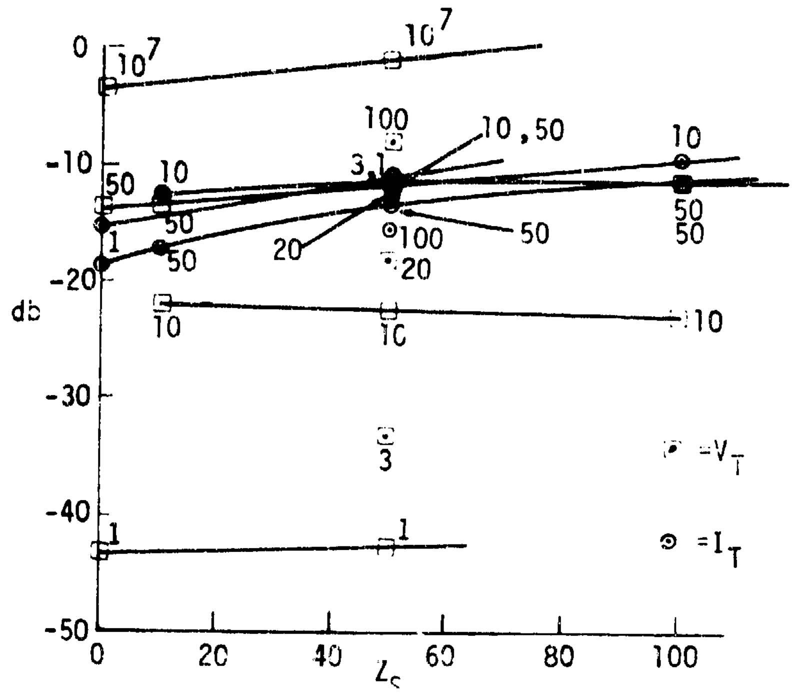


FIGURE 108 MODE 4A BUCK INPUT 1 OUTPUT 2 REGULATOR PULSE P5

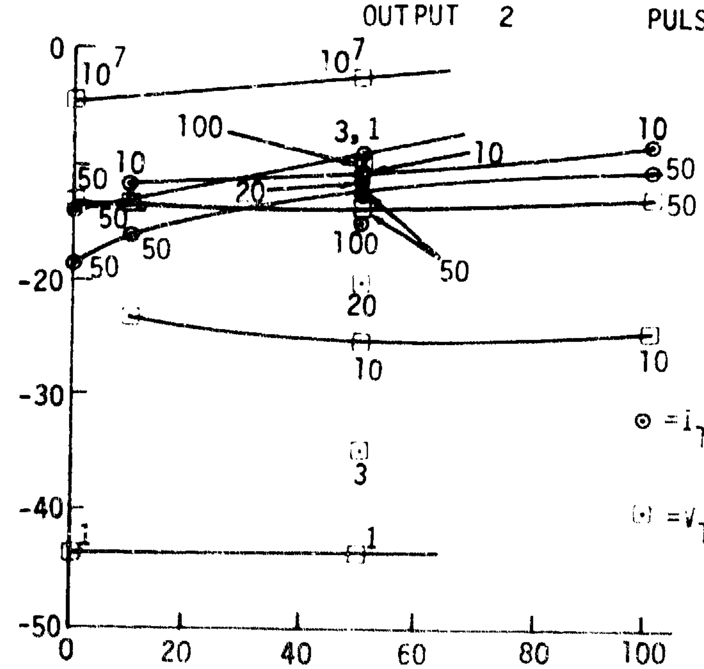


FIGURE 109 MODE 4A BUCK INPUT 2 OUTPUT 1 REGULATOR PULSE P5

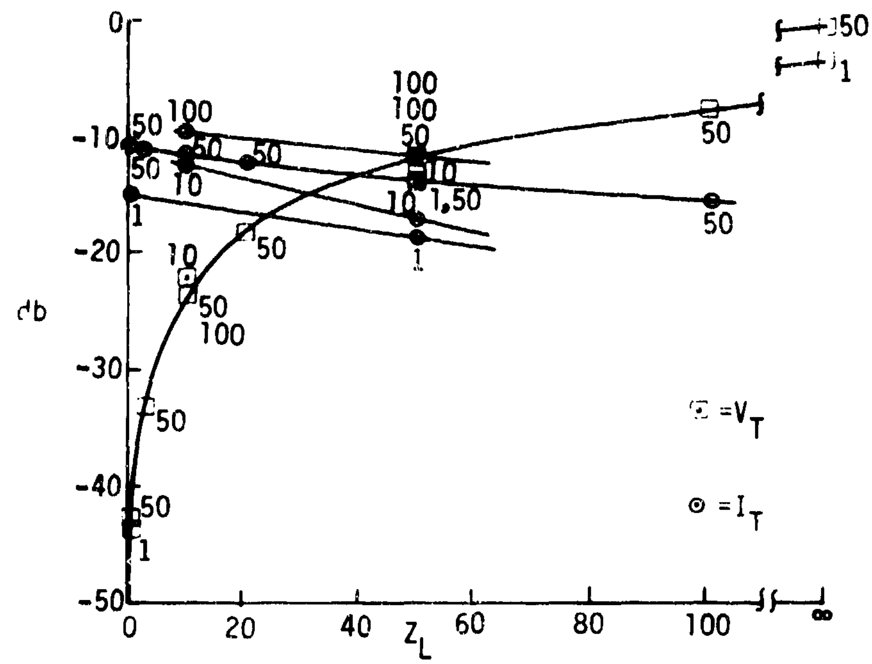


FIGURE 110 MODE 4A BUCK INPUT 1 OUTPUT 2 REGULATOR PULSE P5

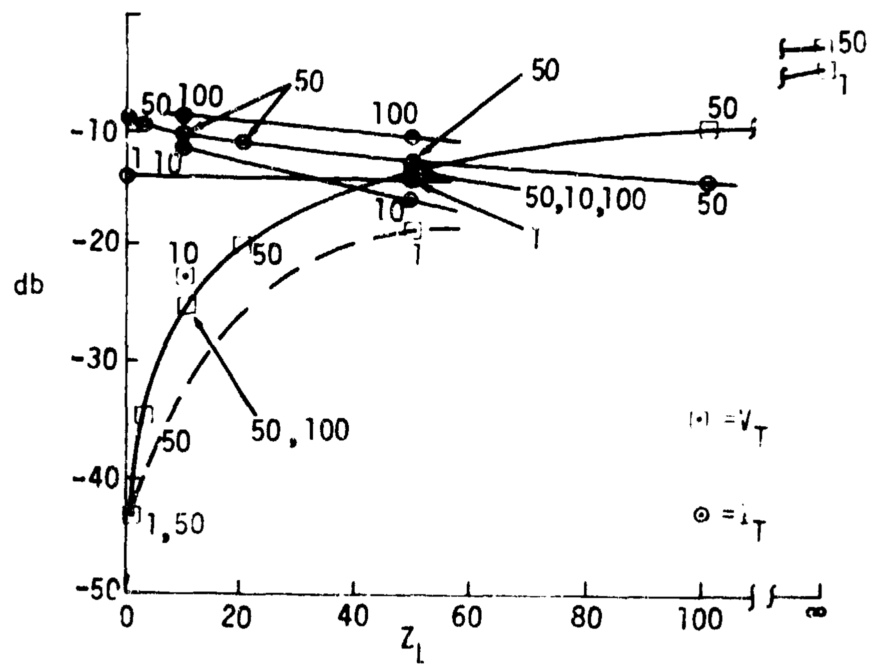


FIGURE 111 MODE 4A BUCK INPUT 1 OUTPUT 2 REGULATOR PULSE P5

4.0 POWER SUBSYSTEM ANALYSIS

The transformer models in terms of ABCD parameters are directly applicable to power system and subsystem computer modeling. A power subsystem, consisting of power wire in conduit feeding a shielded transformer which powers direct buried cable in a lighting string, was modeled and analyzed for EMP propagation. The analysis used the ZAPTRN program.

The computer program ZAPTRN performs basically the same function as ZAPTST. The main difference is that ZAPTRN has the necessary additional subroutines and other software to compute the response of more complicated cascades of elements in addition to the transformer, e.g., transmission-line segments and other networks.

The specific problem was to obtain an approximate solution for the transient coupled from the SAFEGUARD threat field through a 200-foot direct buried cable used to transmit power from a transformer (TF1004) in the RLOB at the RLS to a perimeter lighting system.

A model was postulated consisting of 200 feet of buried cable, terminated at its outer end by the load model depicted in figure 112. The inner end of the cable was attached to the RLOB transformer, whose primary was fed through 50 feet of cable in a 2-inch conduit. The conduit cable was terminated at its far end by the load model depicted in figure 113. The rather large shunt capacitor represents a surge capacitor from bus to ground, while the inductance and resistance approximate the lead inductance and resistance plus the ground connection resistance. The buried cable was assumed to be at a depth of 3 feet in ground, having a relative dielectric constant of 10. andaa conductivity of 1. x 10^{-3} mhos/meter. Any possible shielding effect of the spiral bending which is part of such cables is neglected. In the TF1004 model used, the buried cable was assumed attached to the y-connected side. TF1004 has a Faraday shield.

F0003421
FWKNG901

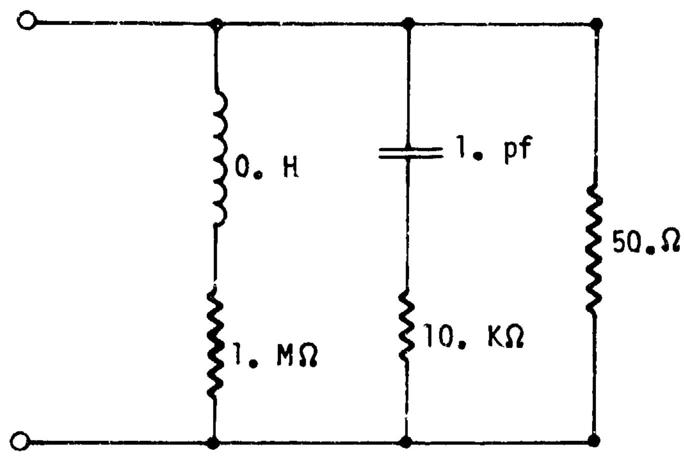


FIGURE 112. ASSUMED TERMINATION IMPEDANCE ATTACHED TO OUTER END OF BURIED CABLE

F0003421
FWKN0901

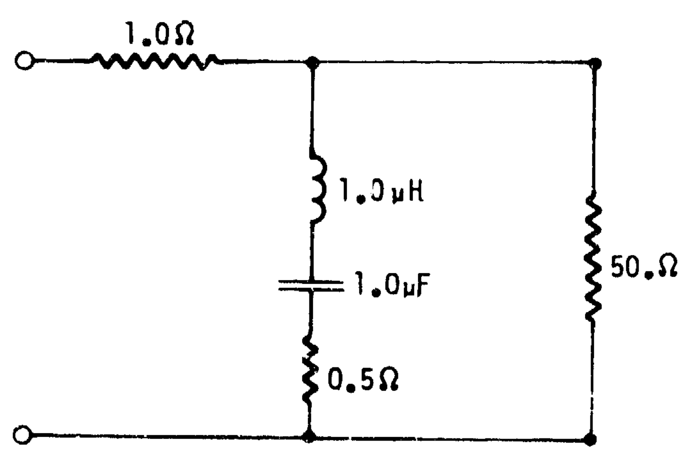


FIGURE 113. ASSUMED LOAD IMPEDANCE ATTACHED TO OUTER END OF 50 FOOT LOAD CABLE

4.0 (Continued)

Table 39 gives a summary of the results obtained from this computation. Also included in the table are the numbers of the figures showing the computed waveforms at various points in the circuit. Bulk (common-mode) quantities were computed.

It is of interest to compare the results shown in table 39 with the results of the computations done with the ZAPTST program with simple resistive terminations on the transformer. For this comparison, a case was selected which used the P-5 pulse shape with TF1004 and about 40 ohm resistive terminations. The latter are roughly in the range of the characteristic impedances of the transmission lines used here. The similarity of the shapes of the primary voltage spectrum at the transformer input for the P-5 pulse and the corresponding computed voltage due to the 200-foot buried cable of the problem can be seen in figures 120 and 121, respectively. It appears that the P-5 pulse used in much of the transformer analysis is reasonably representative of buried cable couplings. The attenuation of the high frequencies is evident.

The ZAPTST case found a voltage transmission ratio for the transformer of -22 dB, which compares with -30 dB above. The corresponding ZAPTST current transmission ratio was -26 dB, which agrees extremely well with the -26.9 dB in table 39.

The difference between the peak current in the load and the peak current at the transformer output seems to come from system resonances. The current and voltage transmission ratios of the output transmission line exhibited the interlaced periodic peaks that are characteristic of the impedance-transforming property of transmission-line segments. The first peak of the current transfer ratio was about 16.5 dB at 2.2 MHz, and 5.0 dB at 7.8 MHz, with decreasing peaks spaced about 5.2 MHz apart, where the line is an odd number of quarter wavelengths long.

TABLE 39. SUMMARY OF COMPUTER RESULTS

PEAK VALUE OF TRANSIENT VOLTAGE AT TRANSFORMER INPUT FIGURE NUMBER 114	8.0 VOLTS
PEAK VALUE OF TRANSIENT CURRENT AT TRANSFORMER INPUT FIGURE NUMBER 115	0.13 AMPS
PEAK VALUE OF TRANSIENT VOLTAGE AT TRANSFORMER OUTPUT FIGURE NUMBER 116	0.22/-0.25 VOLTS
PEAK VALUE OF TRANSIENT CURRENT AT TRANSFORMER OUTPUT FIGURE NUMBER 117	5.7 ma/-5.9 ma
PEAK VALUE OF TRANSIENT VOLTAGE AT LOAD FIGURE NUMBER 118	0.175 VOLTS
PEAK VALUE OF TRANSIENT CURRENT AT LOAD FIGURE NUMBER 119	8 ma
VOLTAGE TRANSMISSION RATIO (TRANSFORMER ONLY)	-30.35 dB
CURRENT TRANSMISSION RATIO (TRANSFORMER ONLY)	-26.88 dB
ENERGY TRANSMISSION RATIO (TRANSFORMER ONLY)	-33 dB

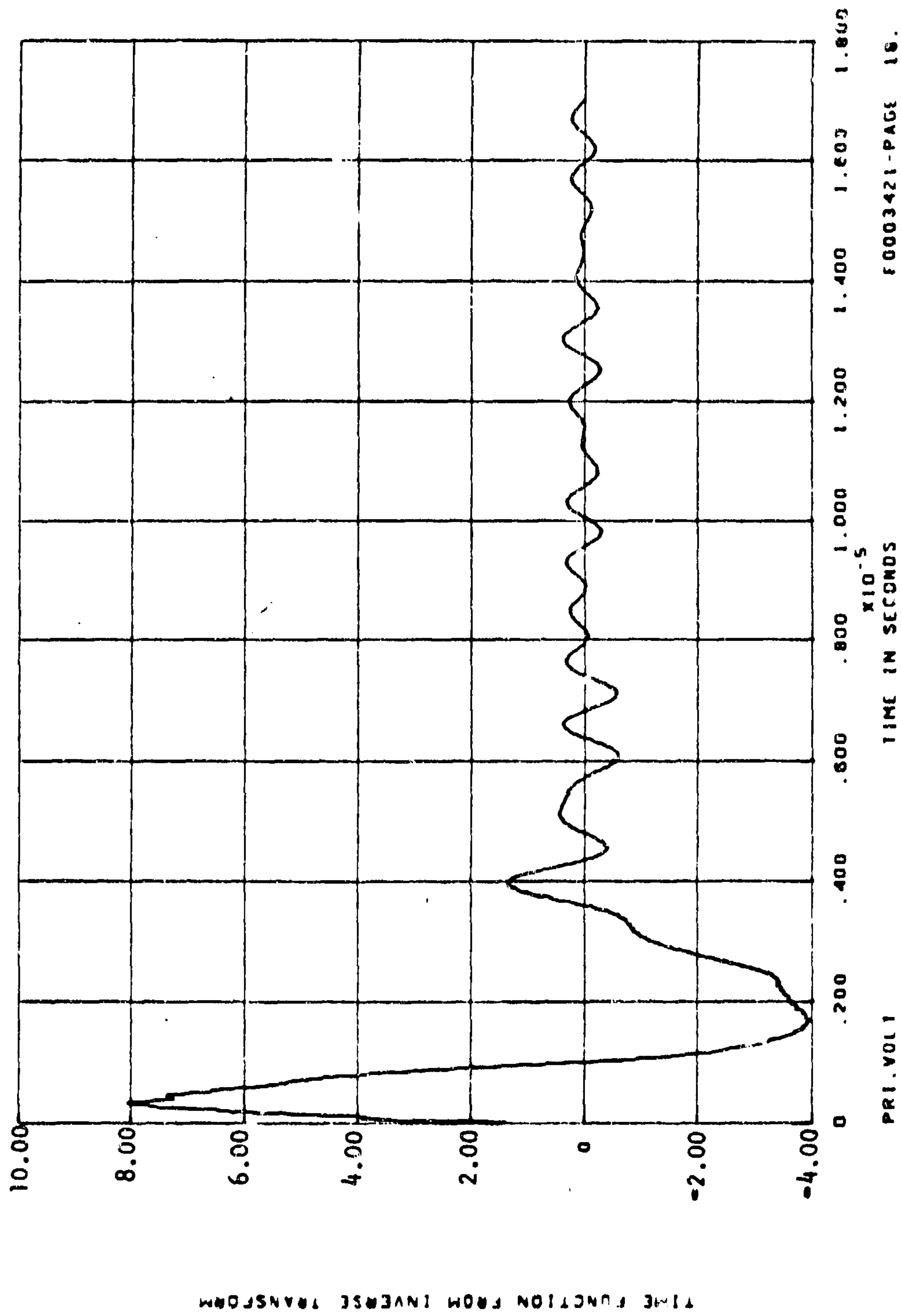


FIGURE 114. TRANSIENT VOLTAGE WAVEFORM AT TRANSFORMER INPUT

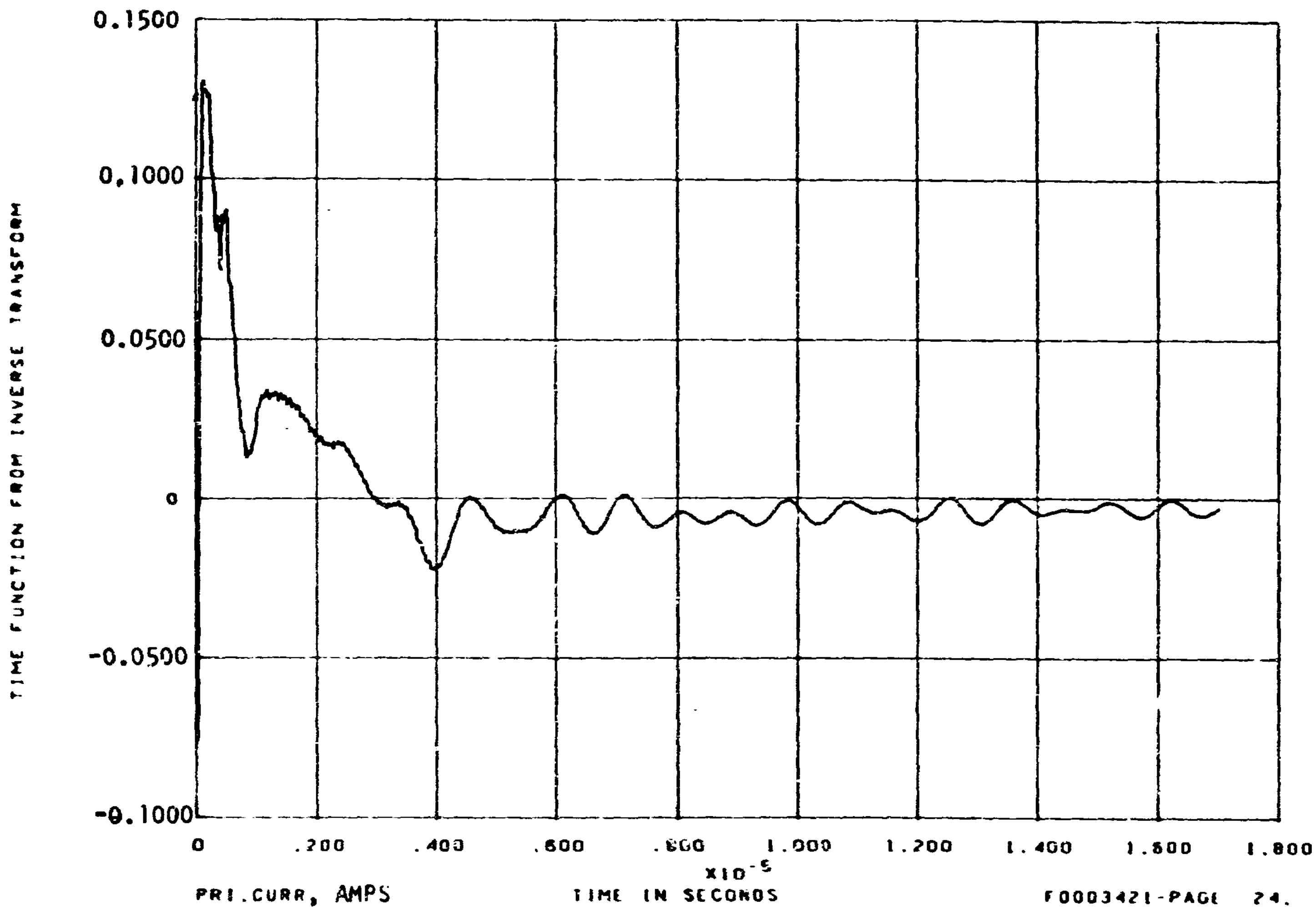


FIGURE 115. TRANSIENT CURRENT WAVEFORM AT TRANSFORMER INPUT

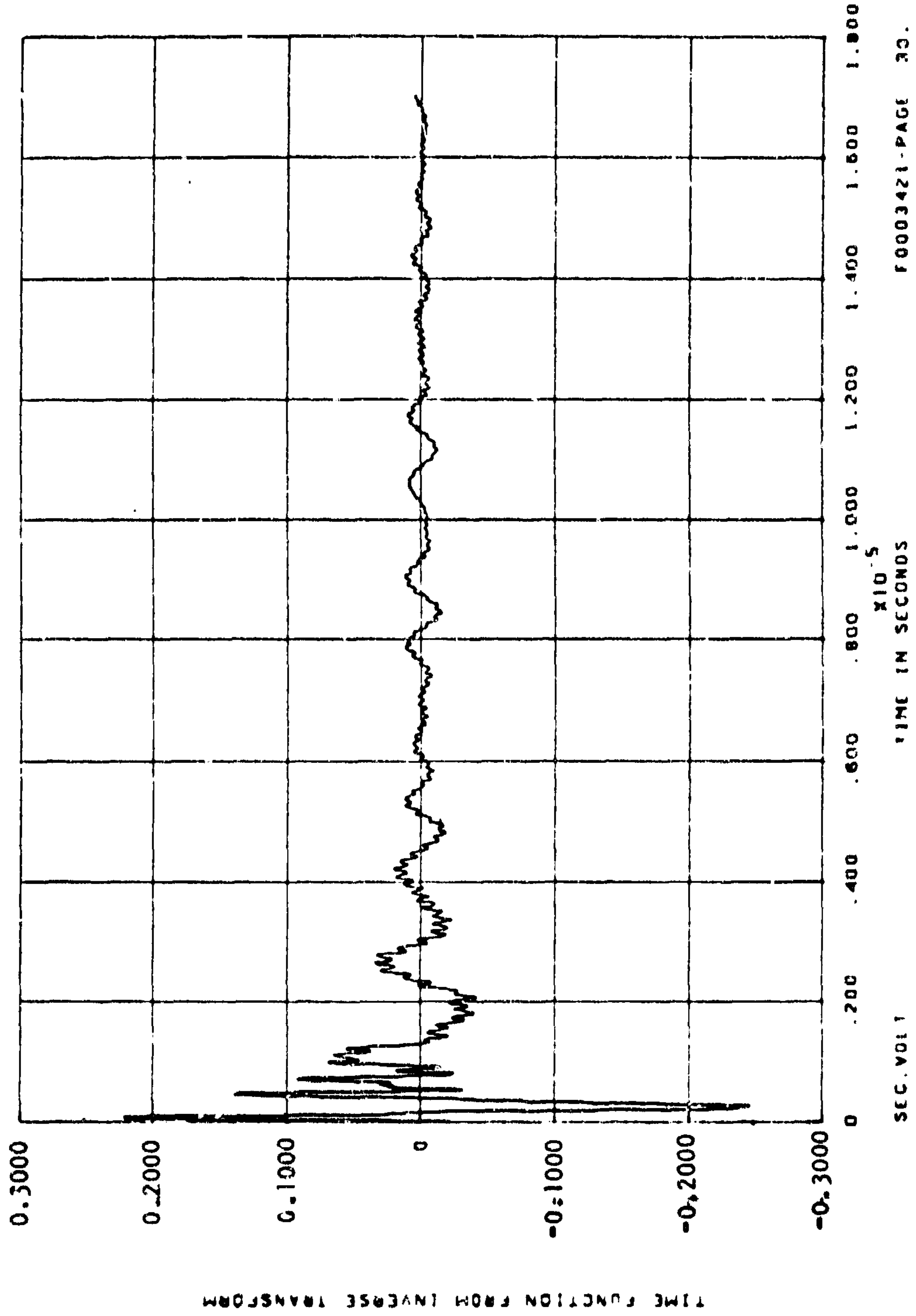


FIGURE 116. TRANSIENT VOLTAGE WAVEFORM AT TRANSFORMER OUTPUT TERMINALS

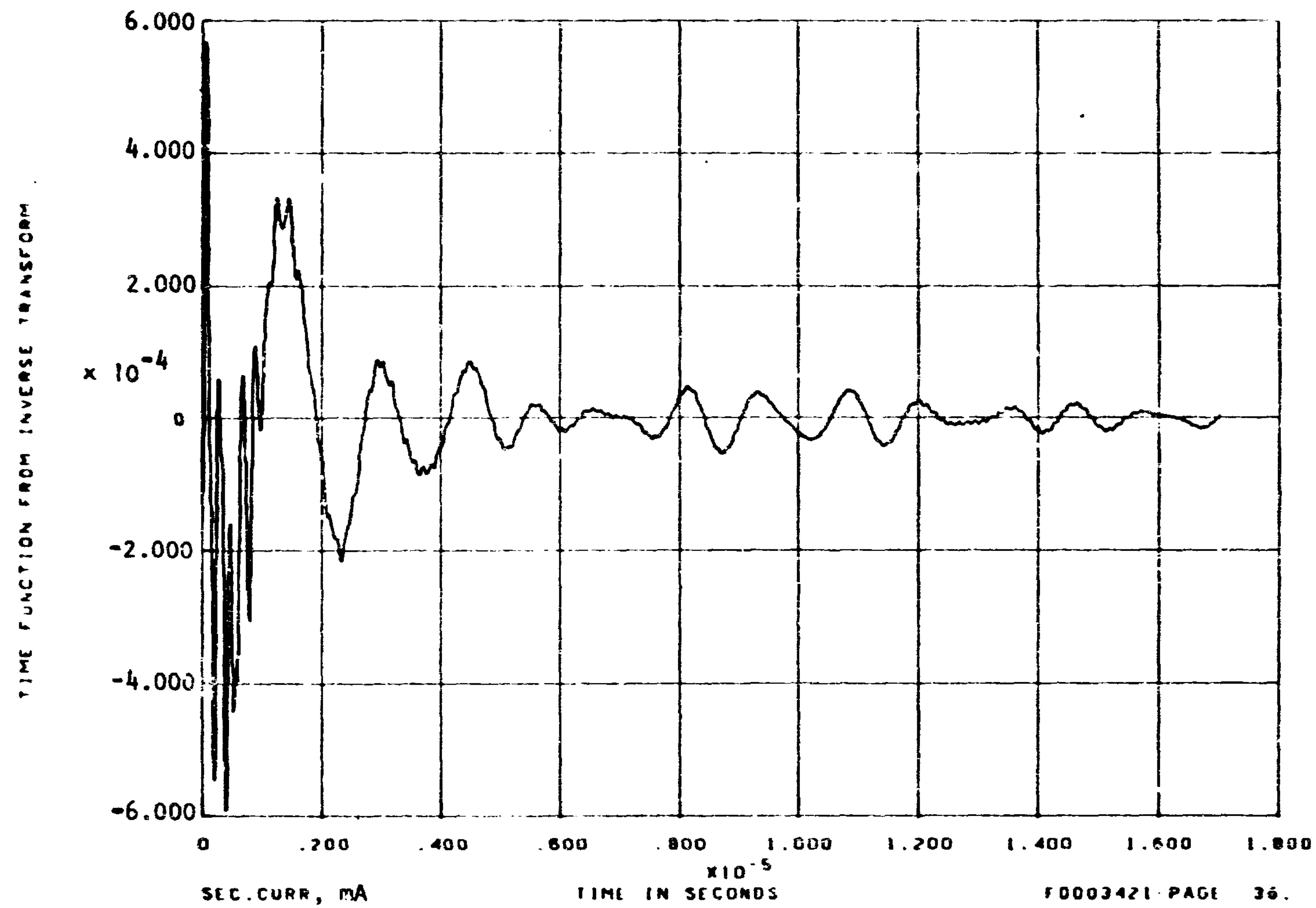


FIGURE 117. TRANSIENT CURRENT WAVEFORM AT TRANSFORMER OUTPUT TERMINALS

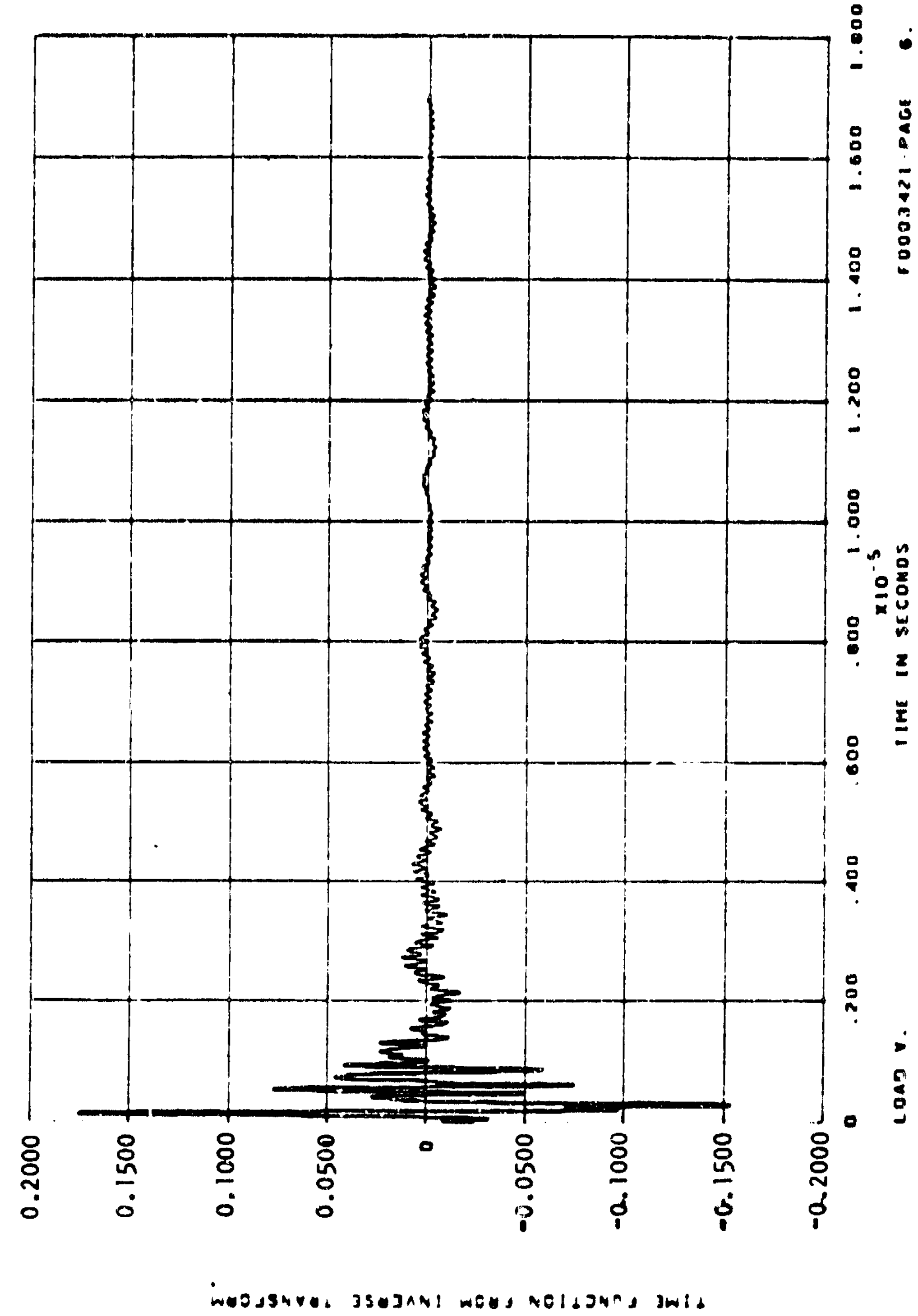


FIGURE 118. TRANSIENT VOLTAGE WAVEFORM AT LOAD TERMINALS

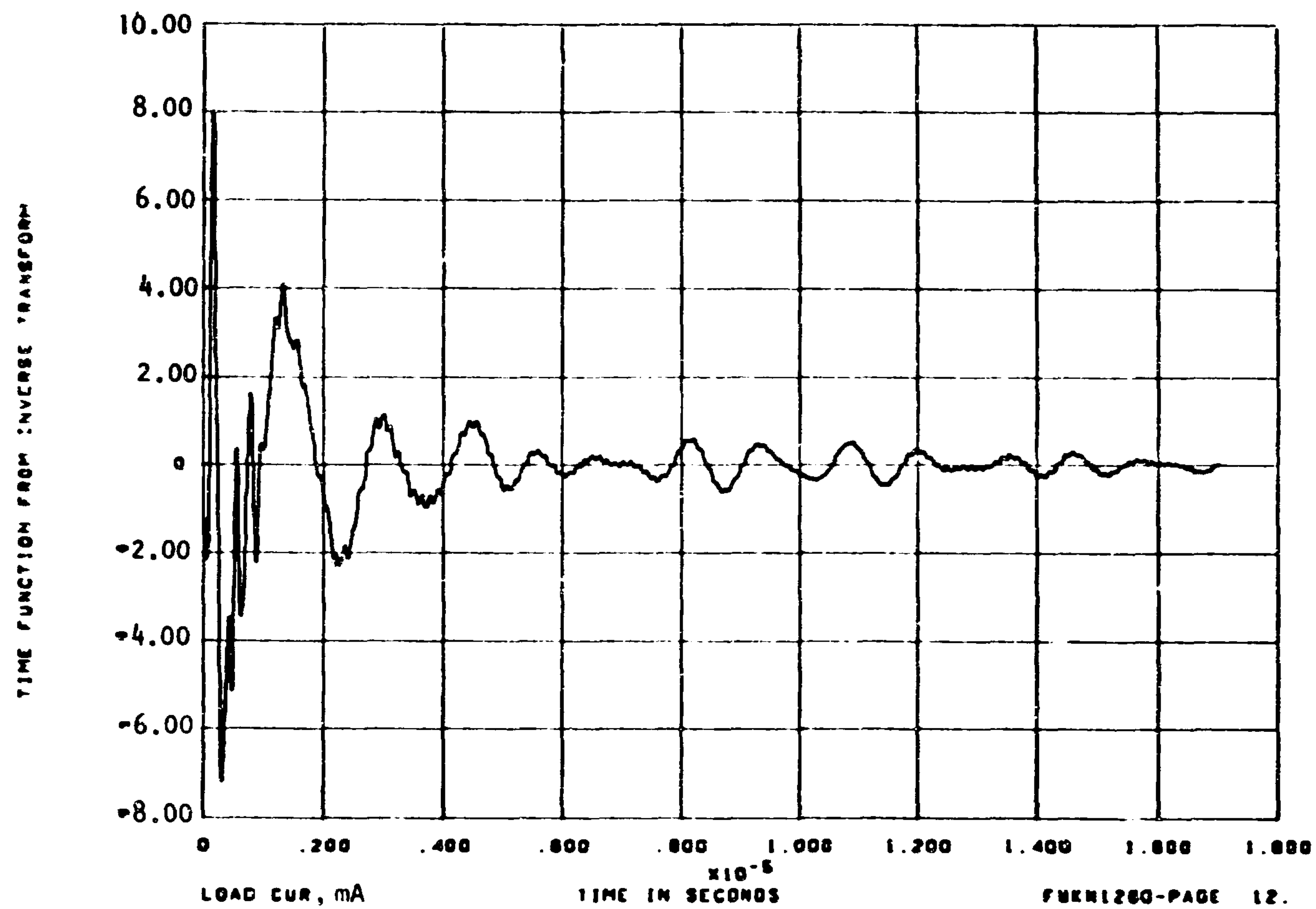


FIGURE 119. TRANSIENT CURRENT WAVEFORM AT LOAD TERMINALS

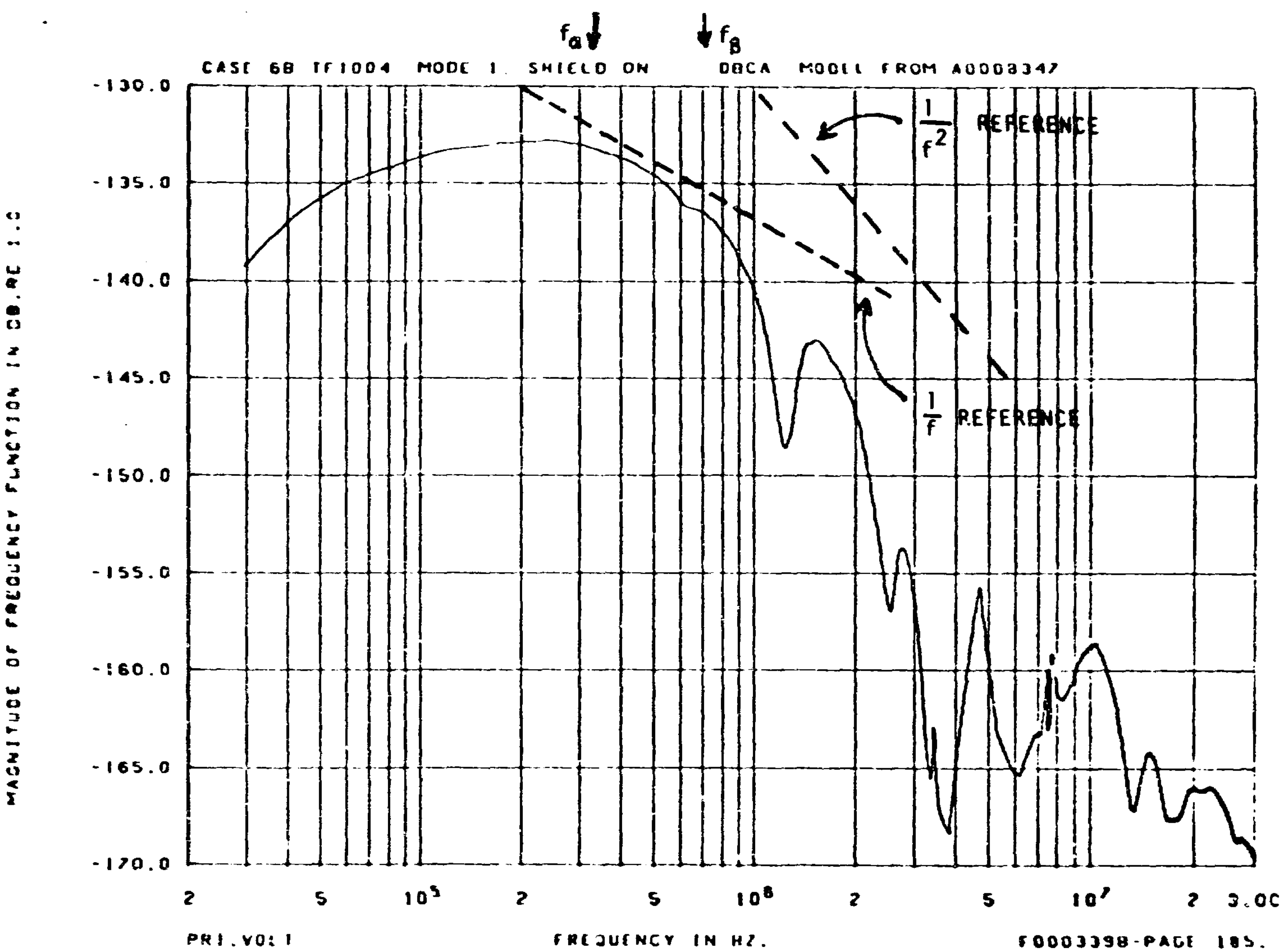


FIGURE 120. MAGNITUDE OF VOLTAGE SPECTRUM AT T-1004 INPUT TERMINALS FROM A ZAPTST CASE USING P-5 PULSE

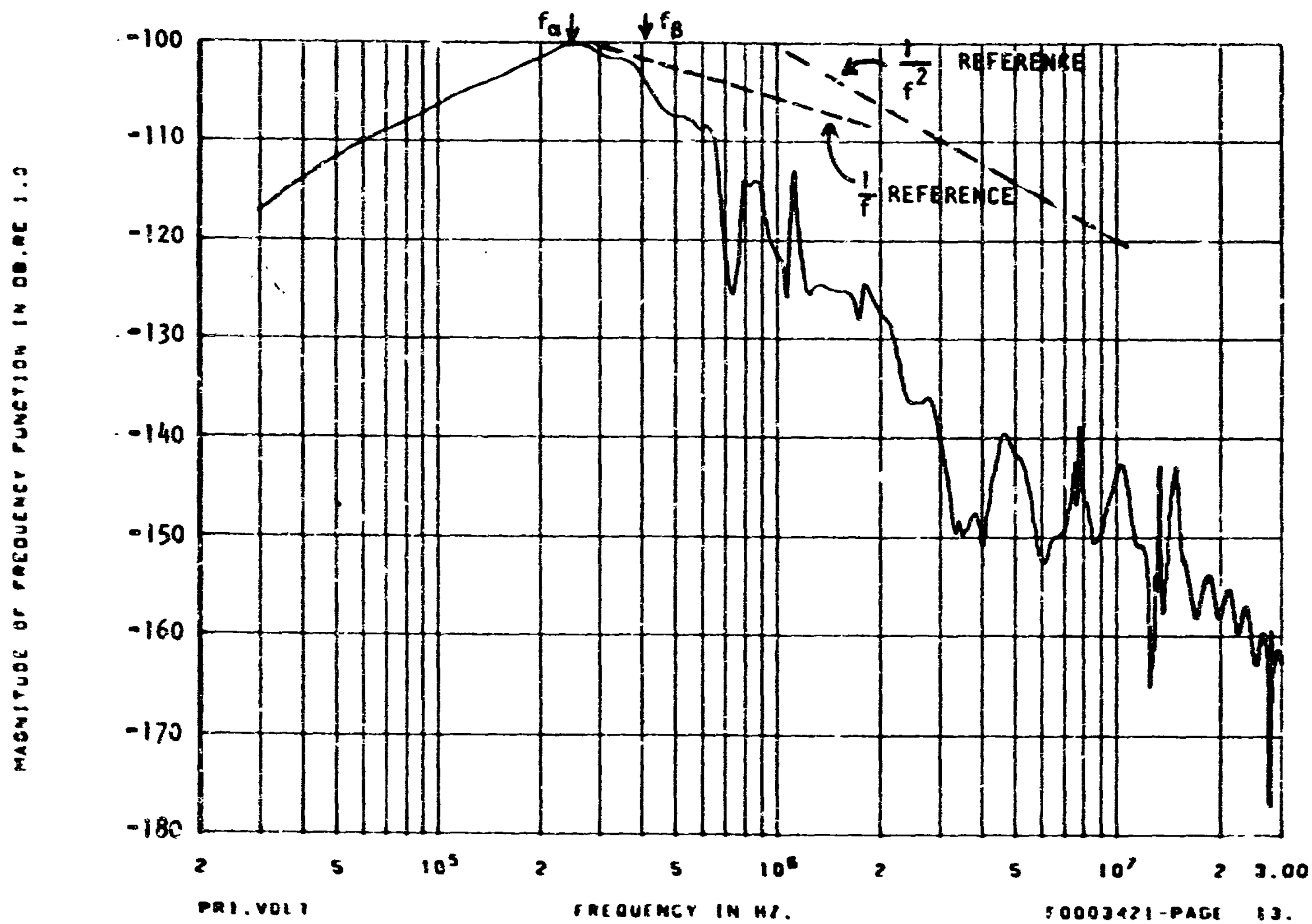


FIGURE 121. MAGNITUDE OF VOLTAGE SPECTRUM AT T-1004 INPUT TERMINALS FROM THE ZAPTRN CASE REPORTED IN TABLE 1

5.0 DATA FLOW EXAMPLE

The methodology for processing the transformer measurements is illustrated preceeding in figures 12 through 15.

The output from each data processing step for one transformer and one load condition is shown following in figures 122 through 144. The transformer data used for this example is for TF12 (see table 1).

An intermediate output (figure 14) from the ABCDOF program is the edited y-parameter data which is shown in figures 122 through 127. The result of this conversion of y parameters to ABCD parameters is shown in figures 128 through 135. The self-consistency of the ABCD parameters is demonstrated by the ABCD determinant, figures 136 and 137. The maximum deviation from a value of 1 for the amplitude of the determinant is seen to be less than 7 percent. Another output from the ABCDOF is the open circuit voltage transfer ratio (figures 136 and 137), which is simply the inverse of the A parameter (figure 2). It is clear that the most important region in figure 138 is the highest amplitude region. The same is true for the inverse of the other ABCD parameters. The SHAKER routine, figure 14, heavily weighs the data values having the largest amplitude. Consequently, for the best results, SHAKER is applied to the inverted ABCD-parameter data. The unloaded voltage transfer ratio from ABCDOF can be compared from that calculated by ZAPTST (for $Z_L = 10^7 \Omega$) as an accuracy check.

The transformer pulse response is calculated by ZAPTST using either the full number (1024) of the data points or the SHAKER output. Some ZAPTST results for transformer TF12 are shown in figures 140 through 144. The impedances used for these figures were $Z_S = 15\Omega$, $Z_L = 10\Omega$, with pulse P-5 (case 4B, table 6). The loaded voltage transfer ratio, the input and output voltage pulses, and the input and output pulse transforms are shown.

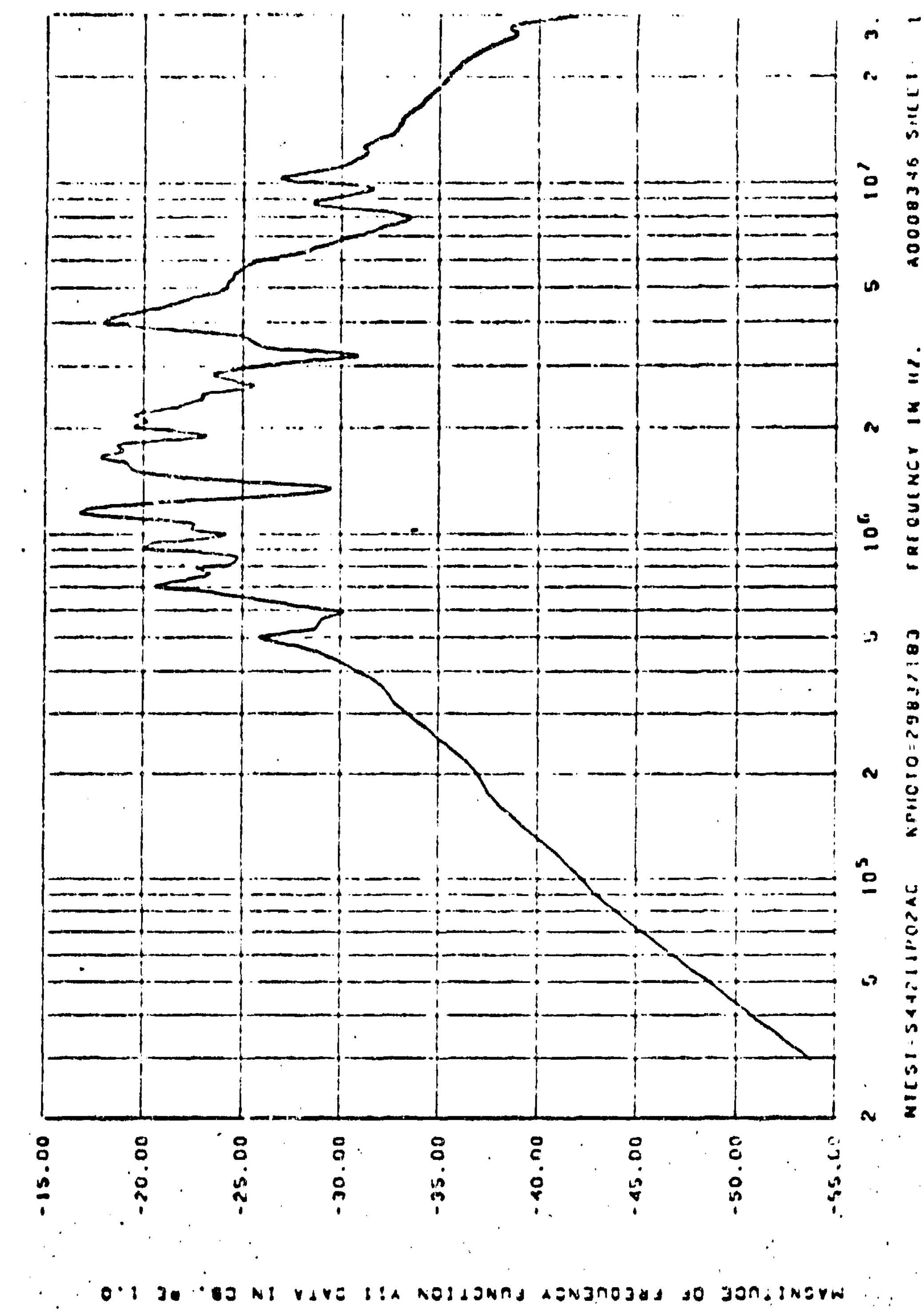


FIGURE 122. TF12 Y11 AMPLITUDE DATA

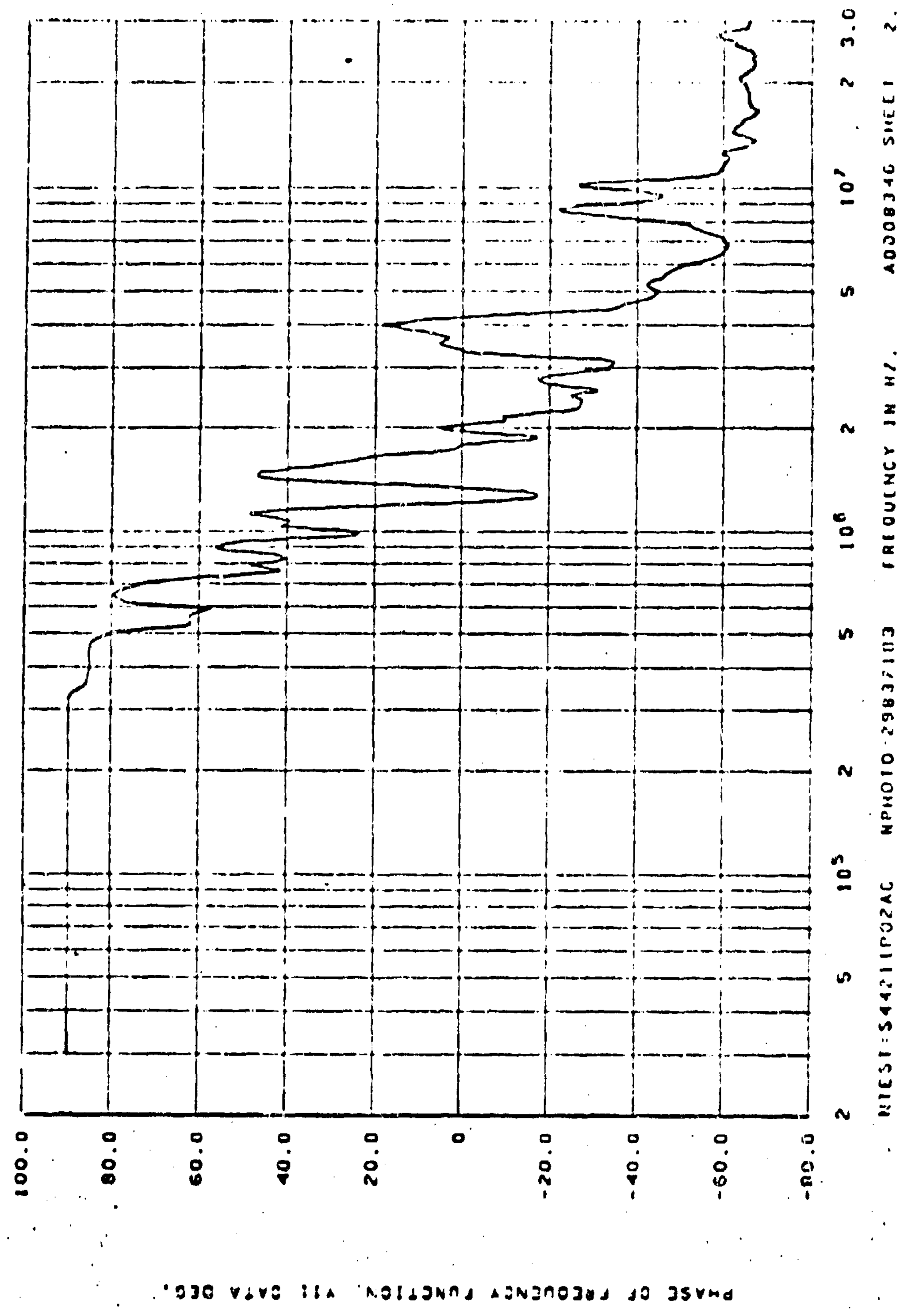


FIGURE 123. TF12 Y11 PHASE DATA

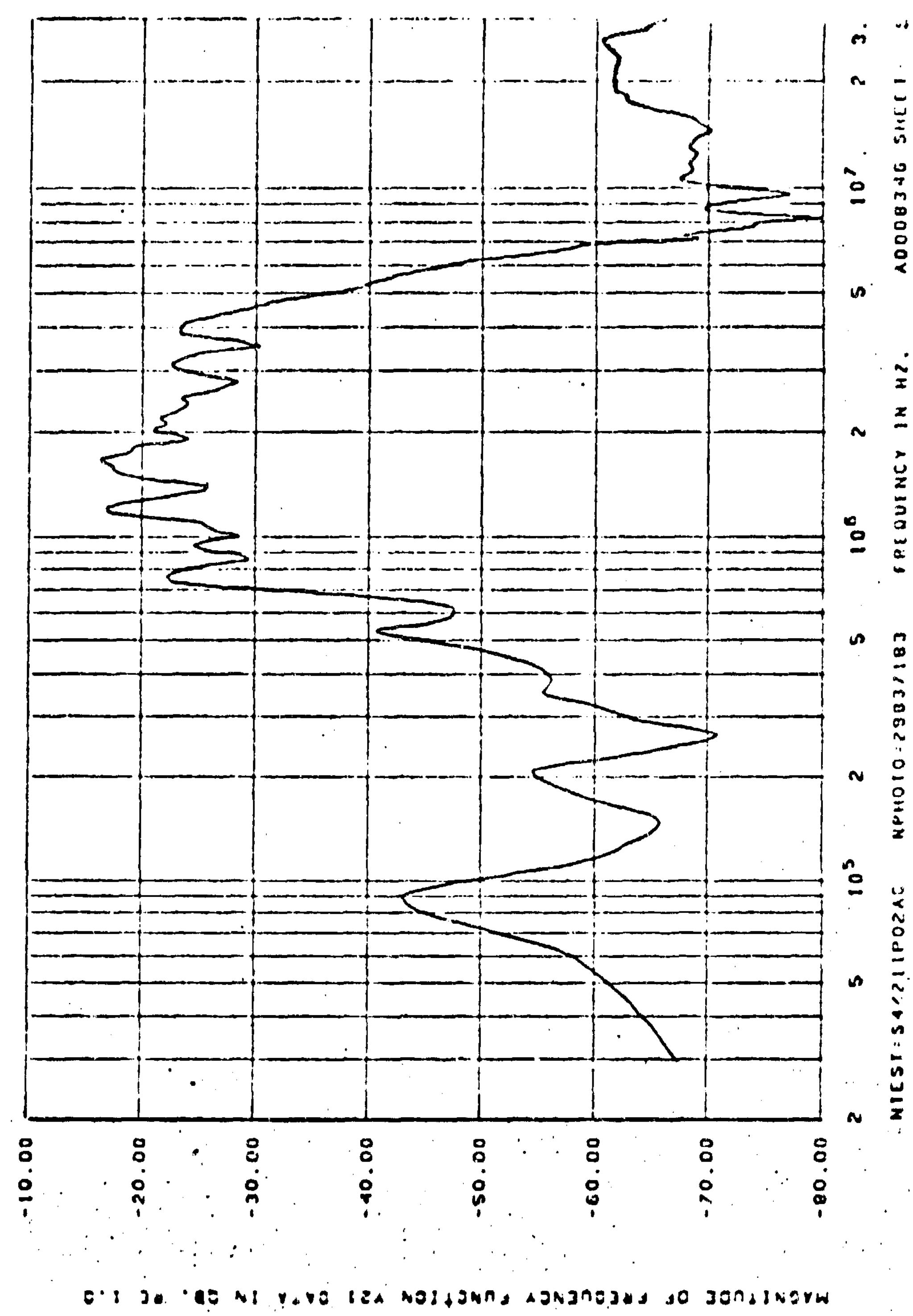


FIGURE 124. TF12 Y12 AMPLITUDE DATA

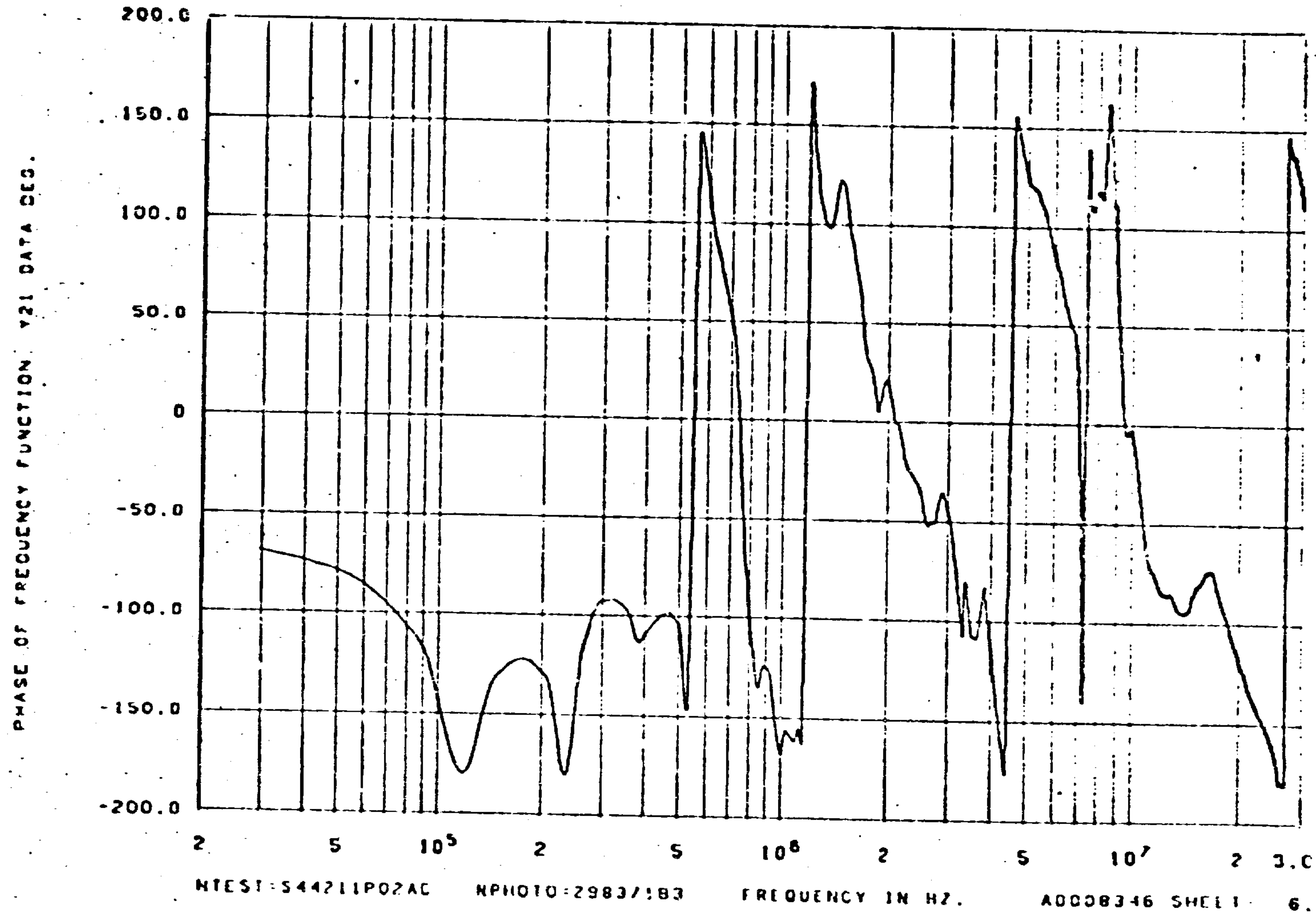


FIGURE 125. TF12 Y12 PHASE DATA

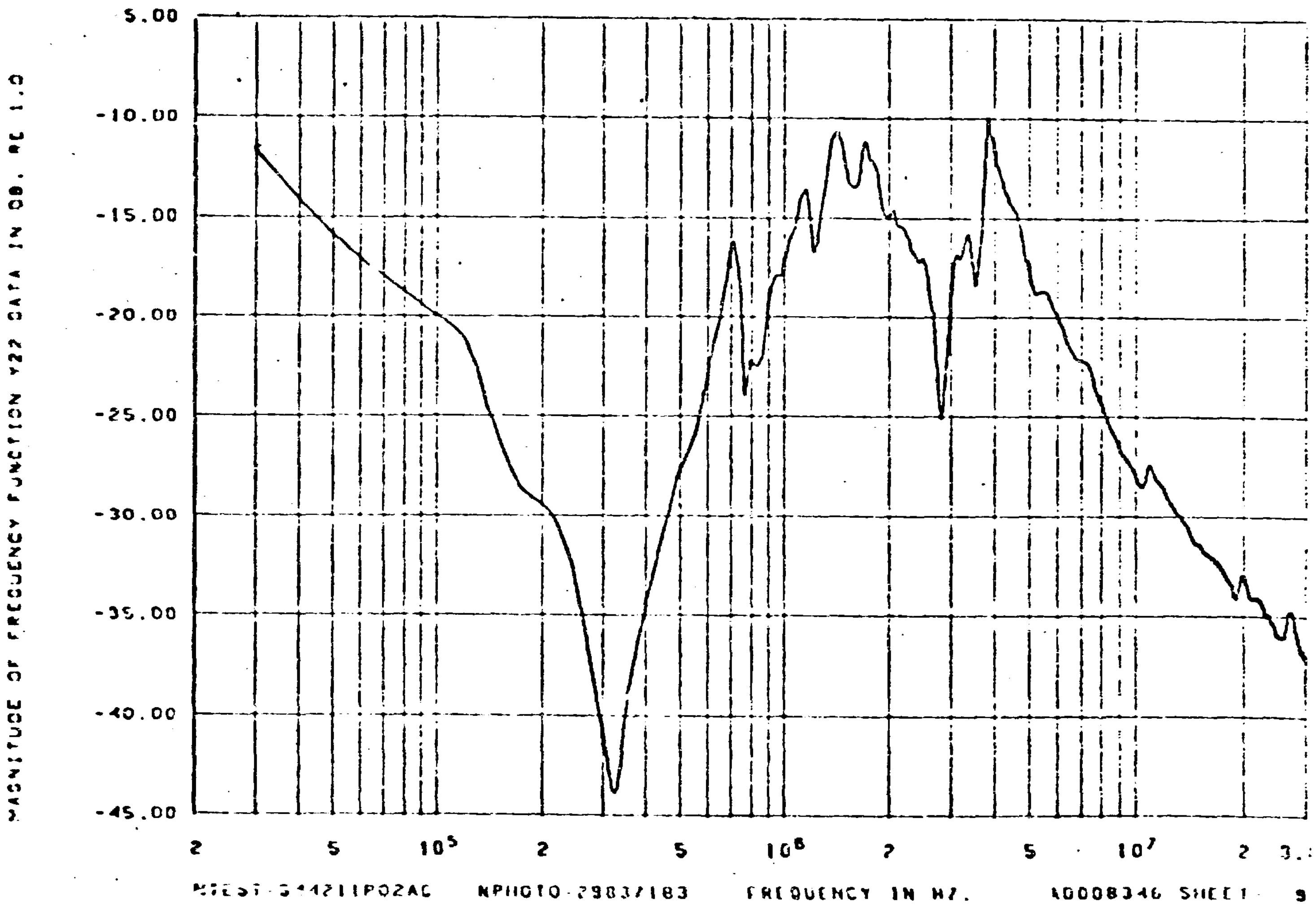


FIGURE 126. TF12 Y22 AMPLITUDE DATA

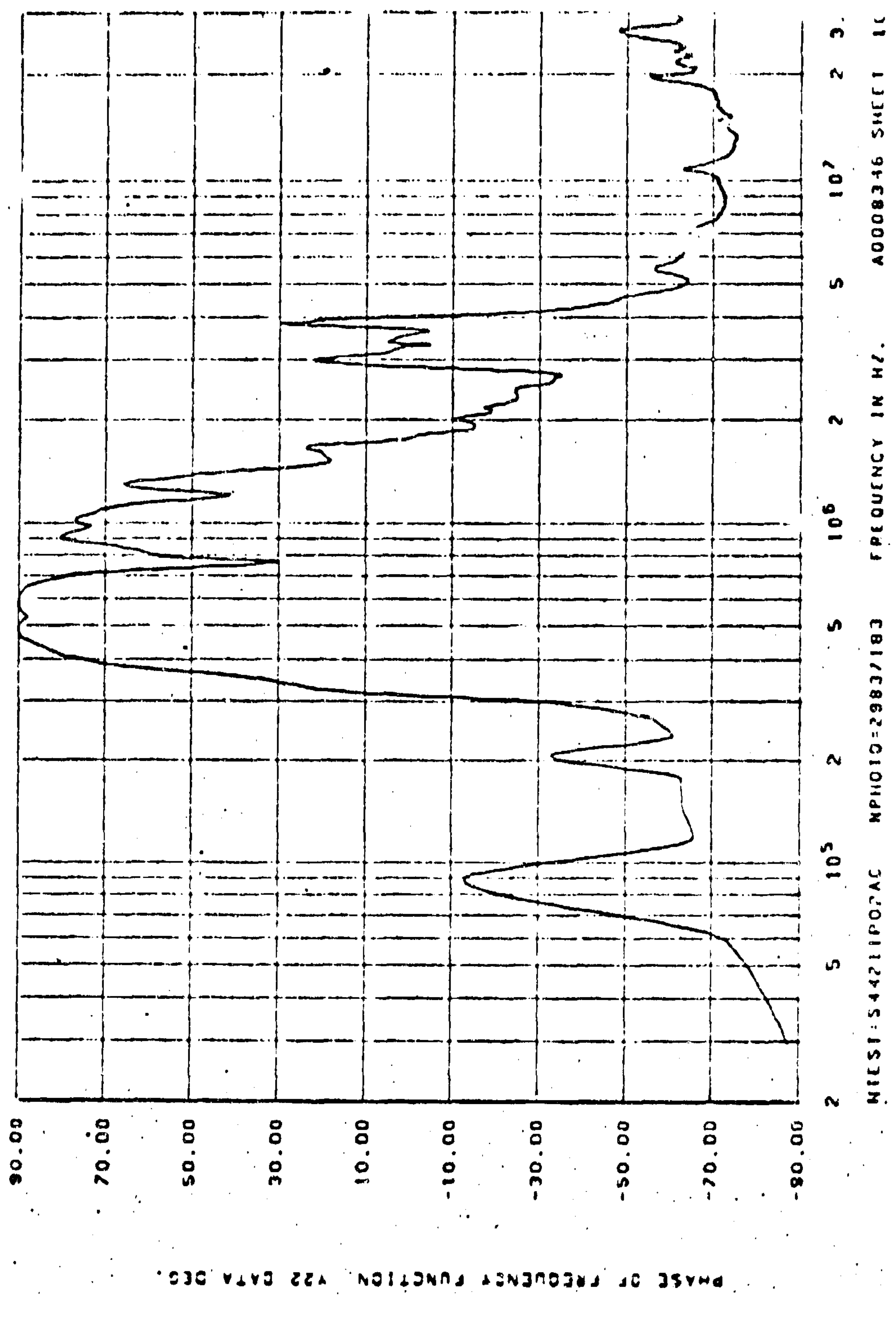


FIGURE 127. TF12 Y22 PHASE DATA

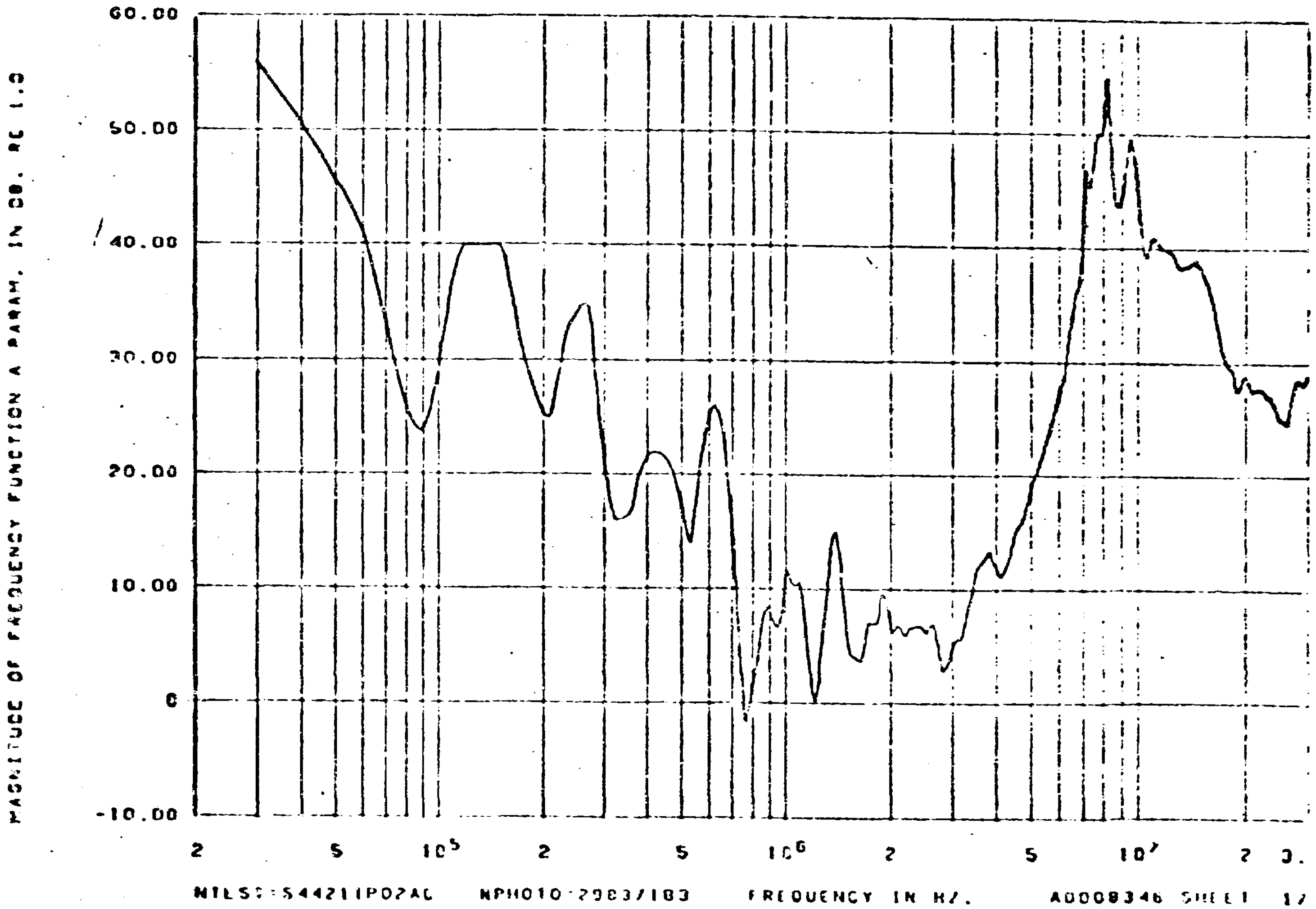


FIGURE 128. TF12 A PARAMETER MAGNITUDE

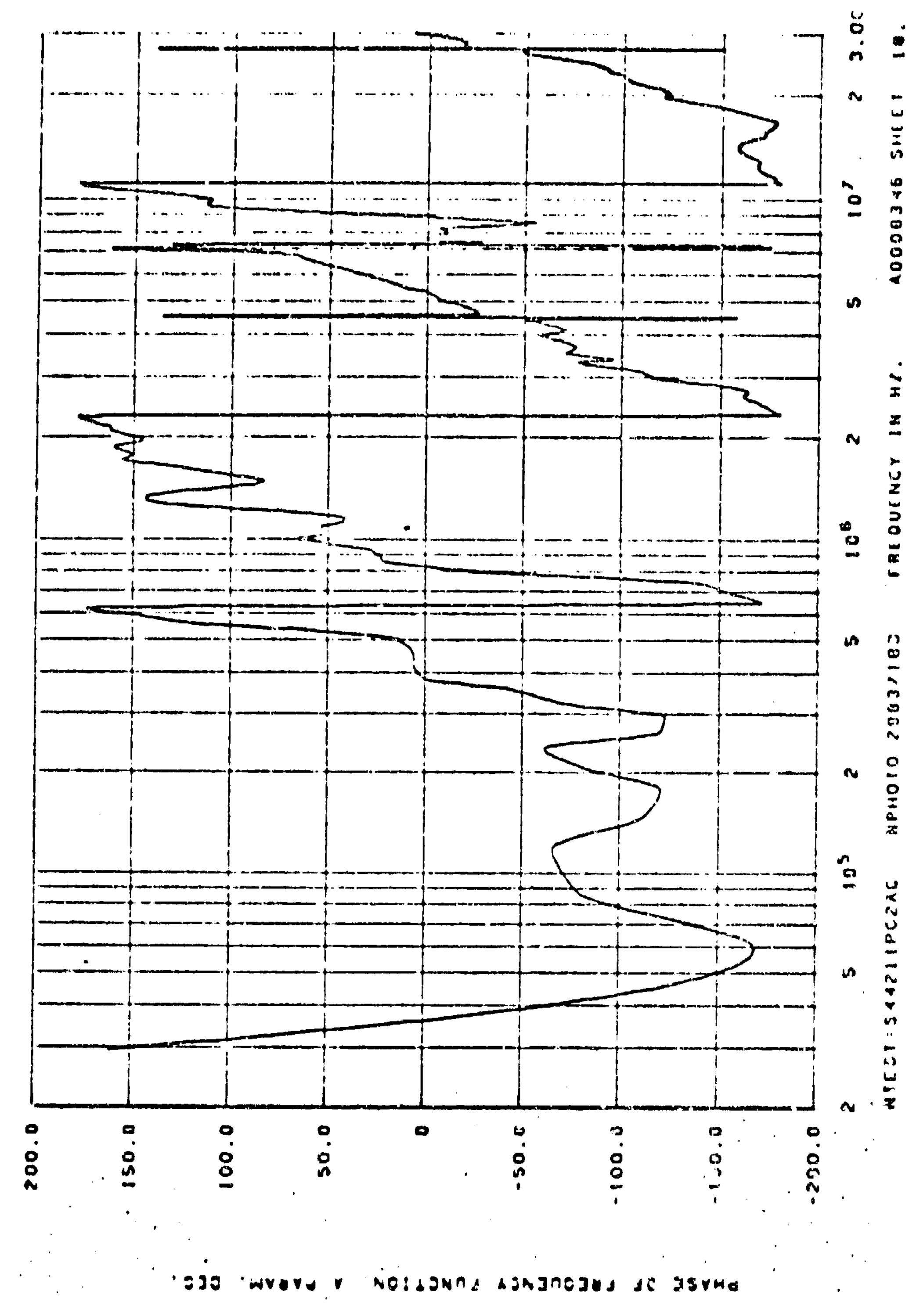


FIGURE 129. TF12 A PARAMETER PHASE

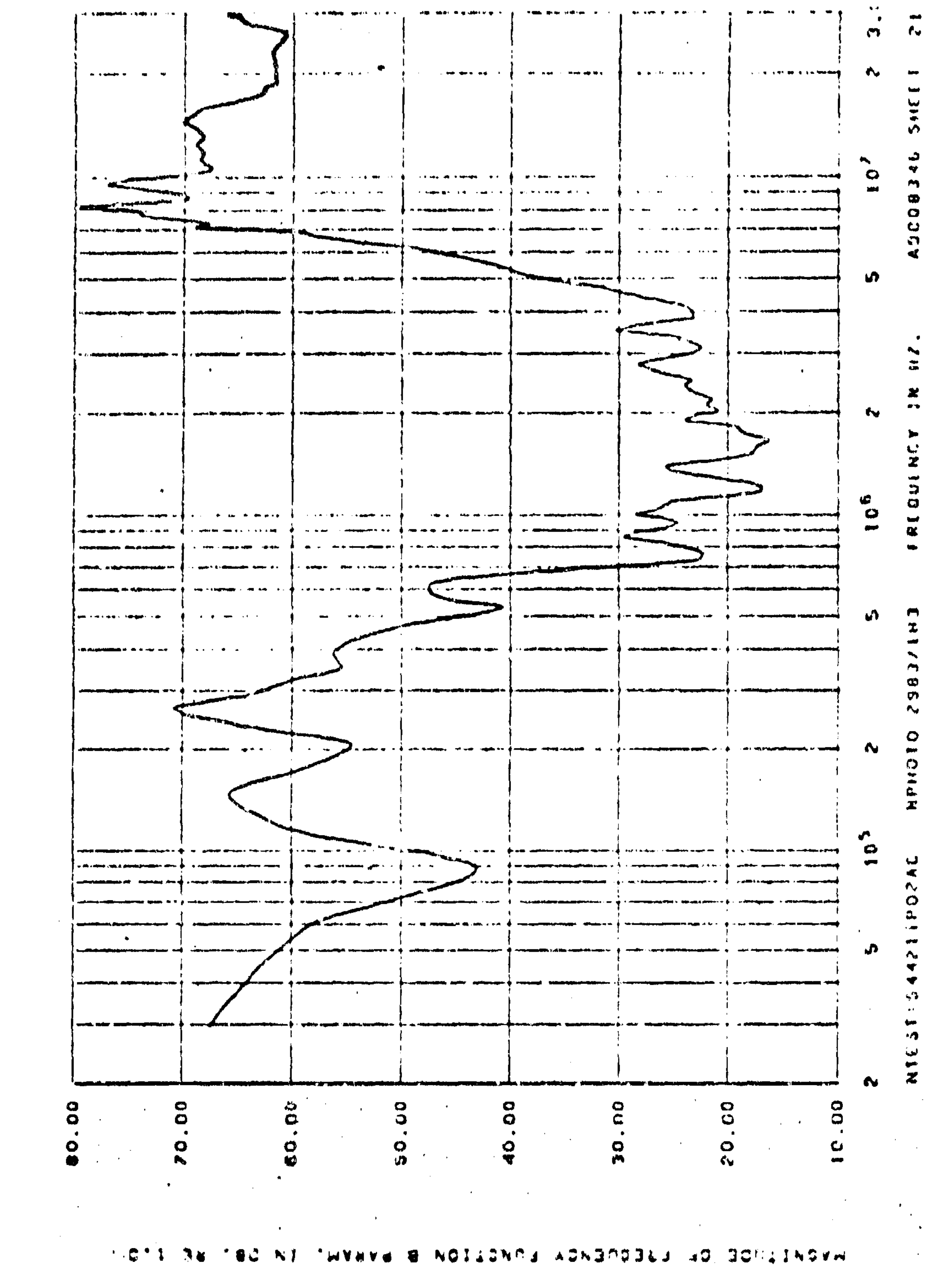


FIGURE 130. TF12 B PARAMETER MAGNITUDE

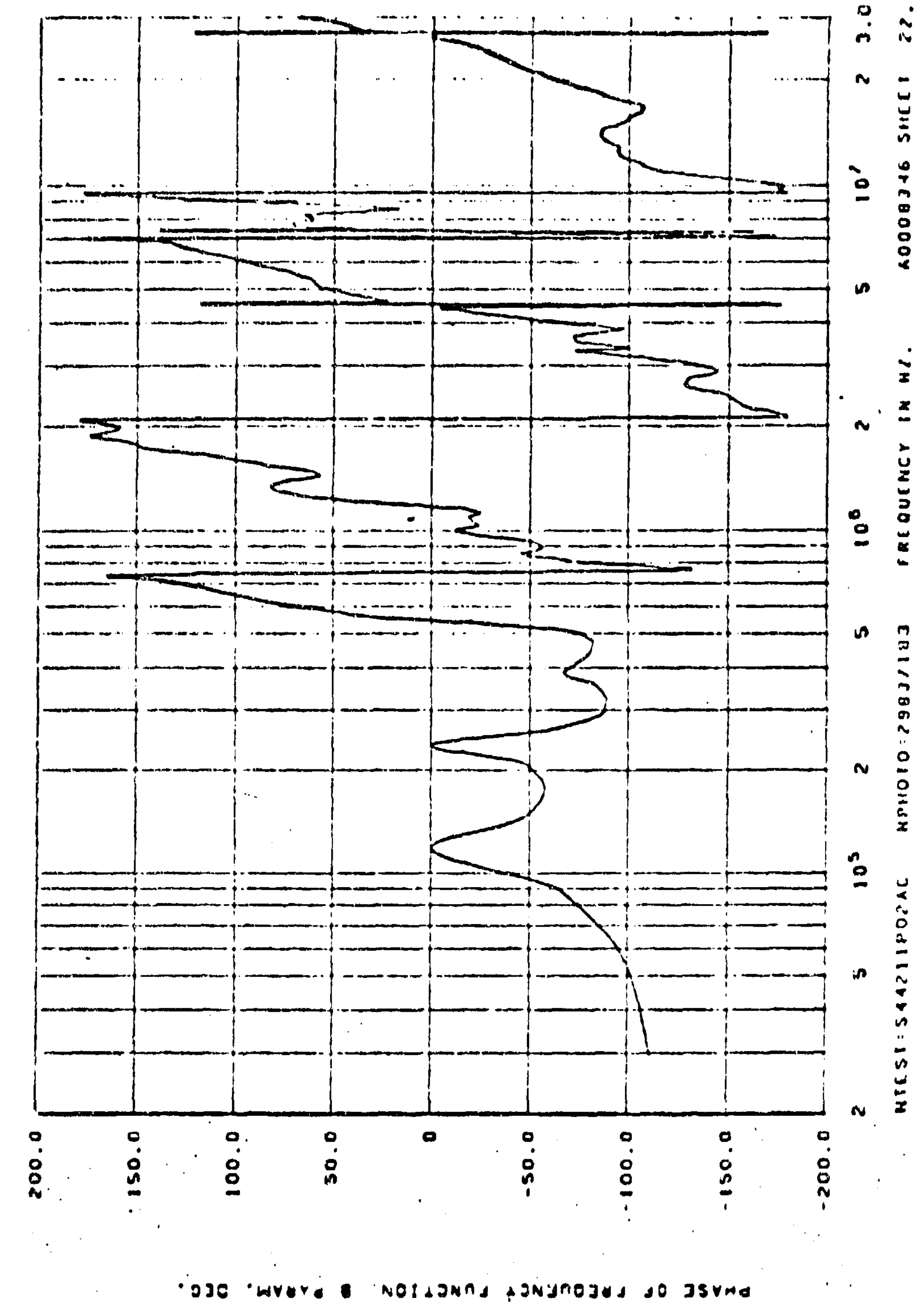


FIGURE 131. TF12 B PARAMETER PHASE

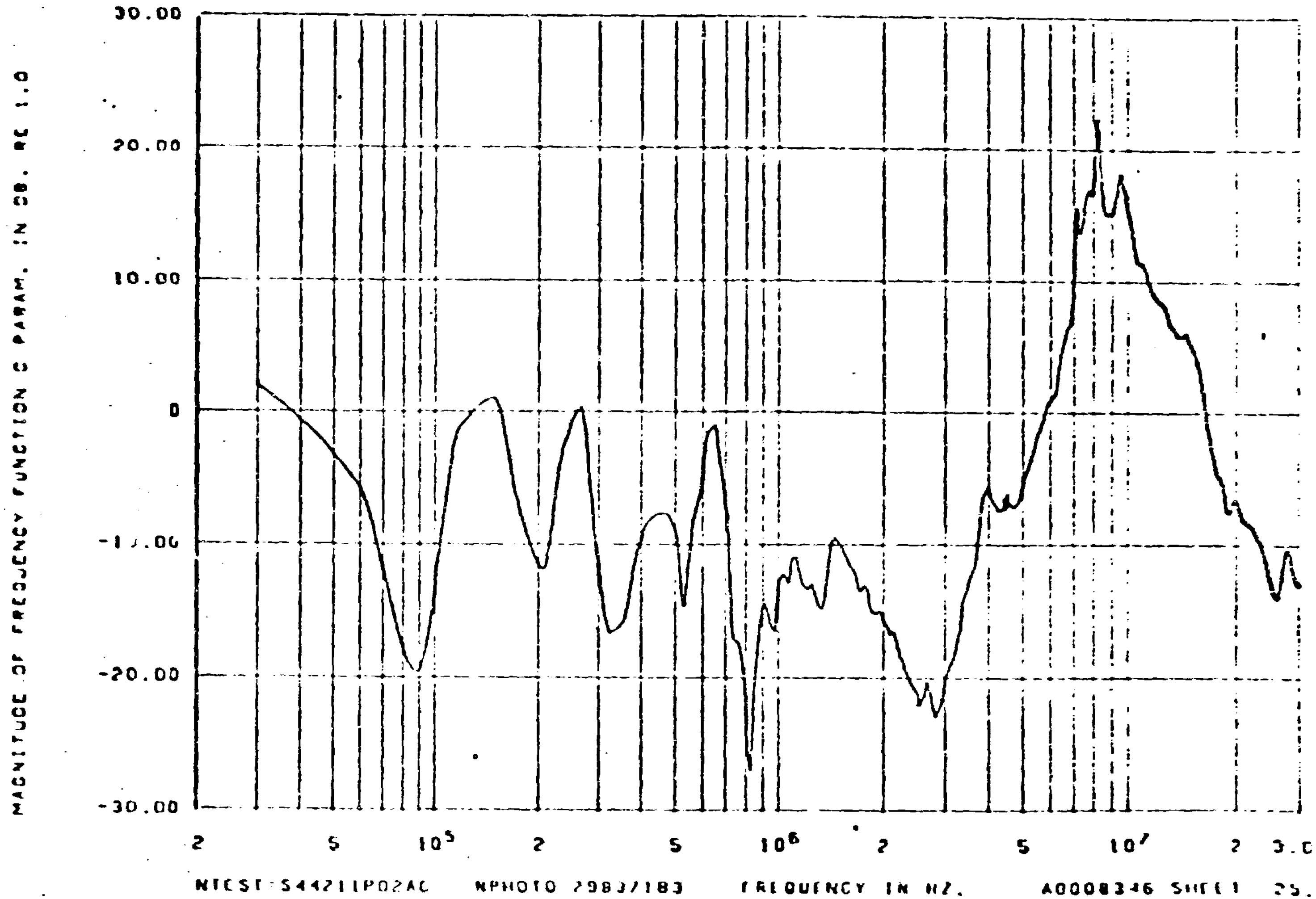


FIGURE 132. TF12 C PARAMETER MAGNITUDE

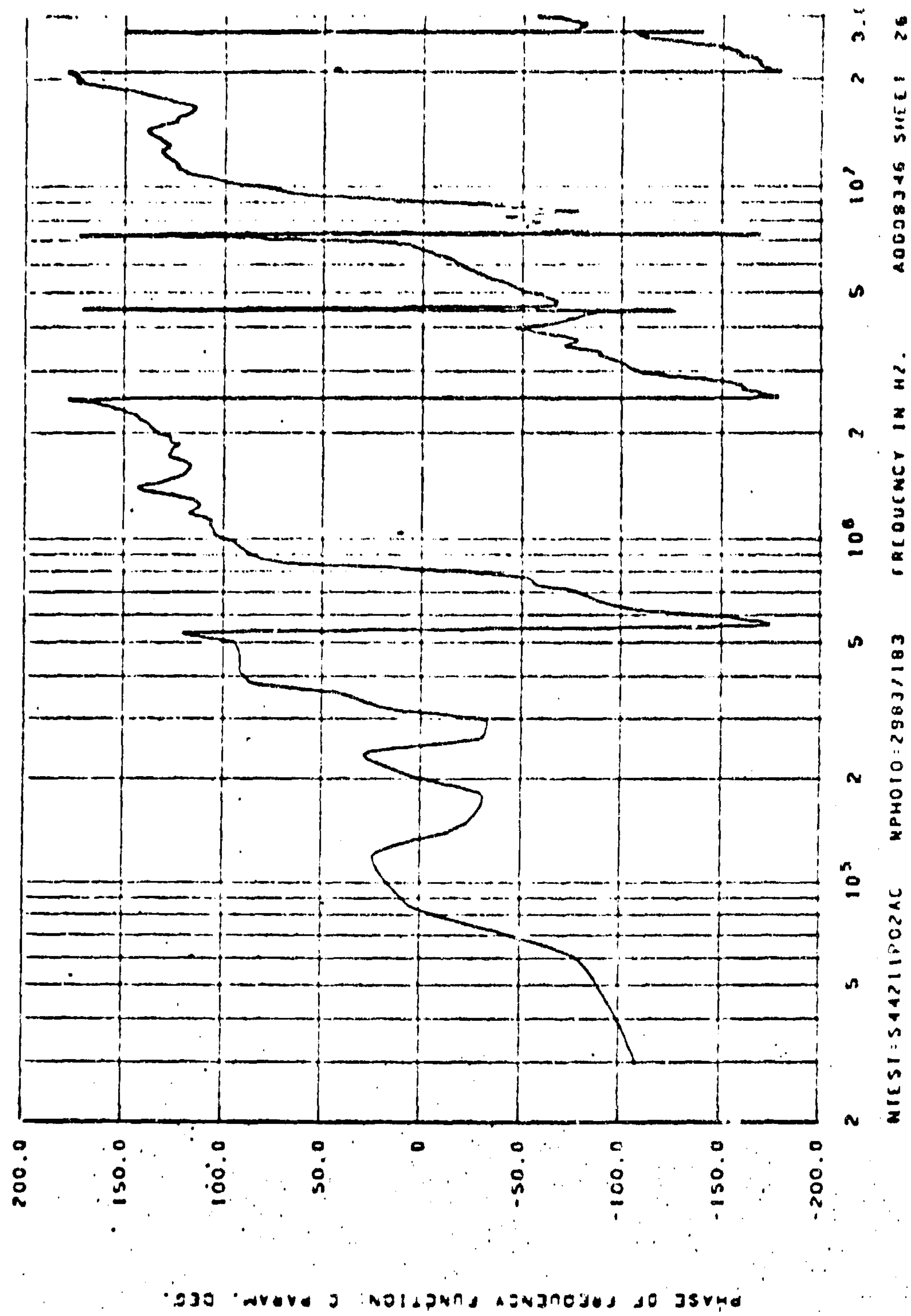


FIGURE 133. TF12 C PARAMETER PHASE

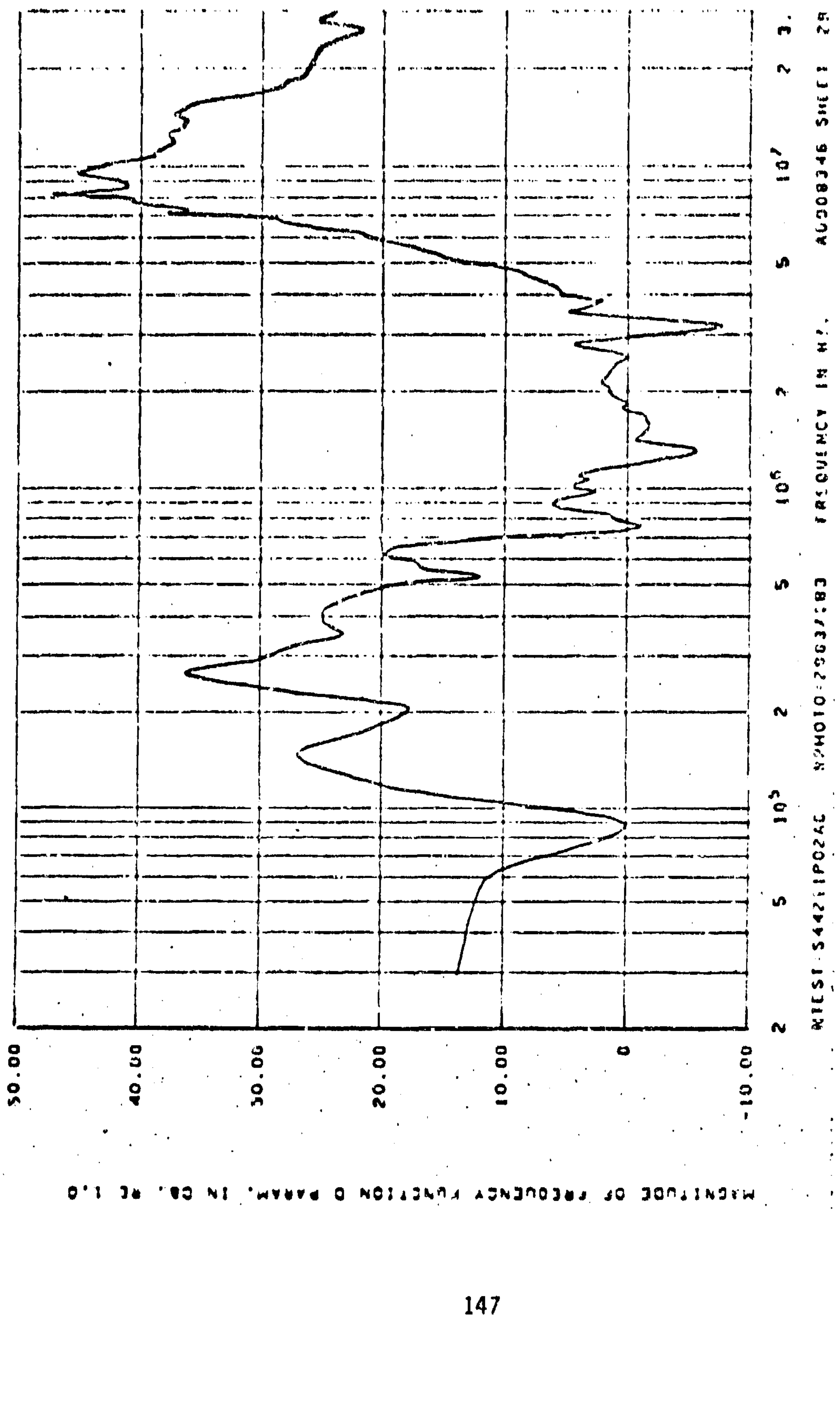


FIGURE 134. TF12 D PARAMETER MAGNITUDE

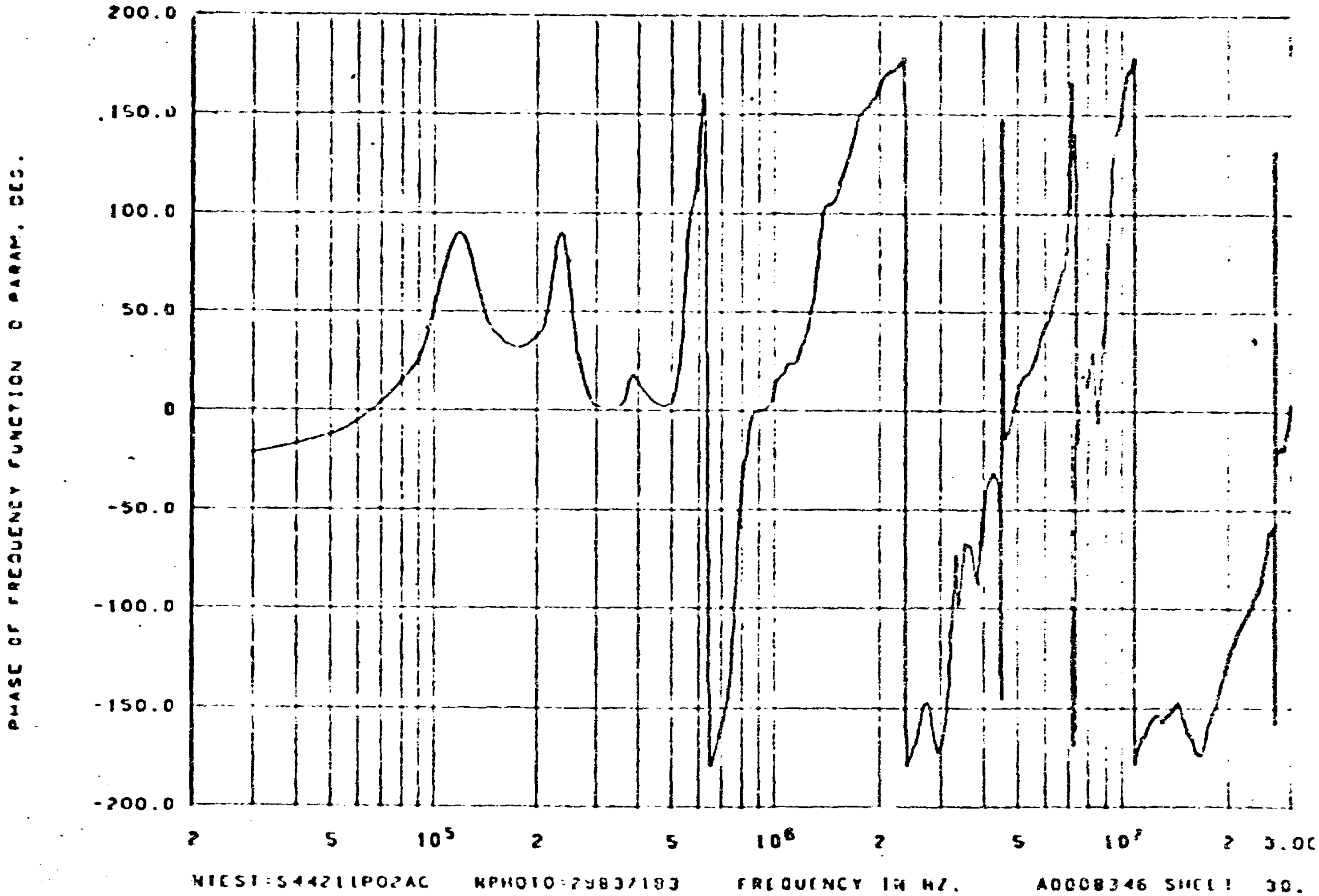


FIGURE 135. TF12 D PARAMETER PHASE

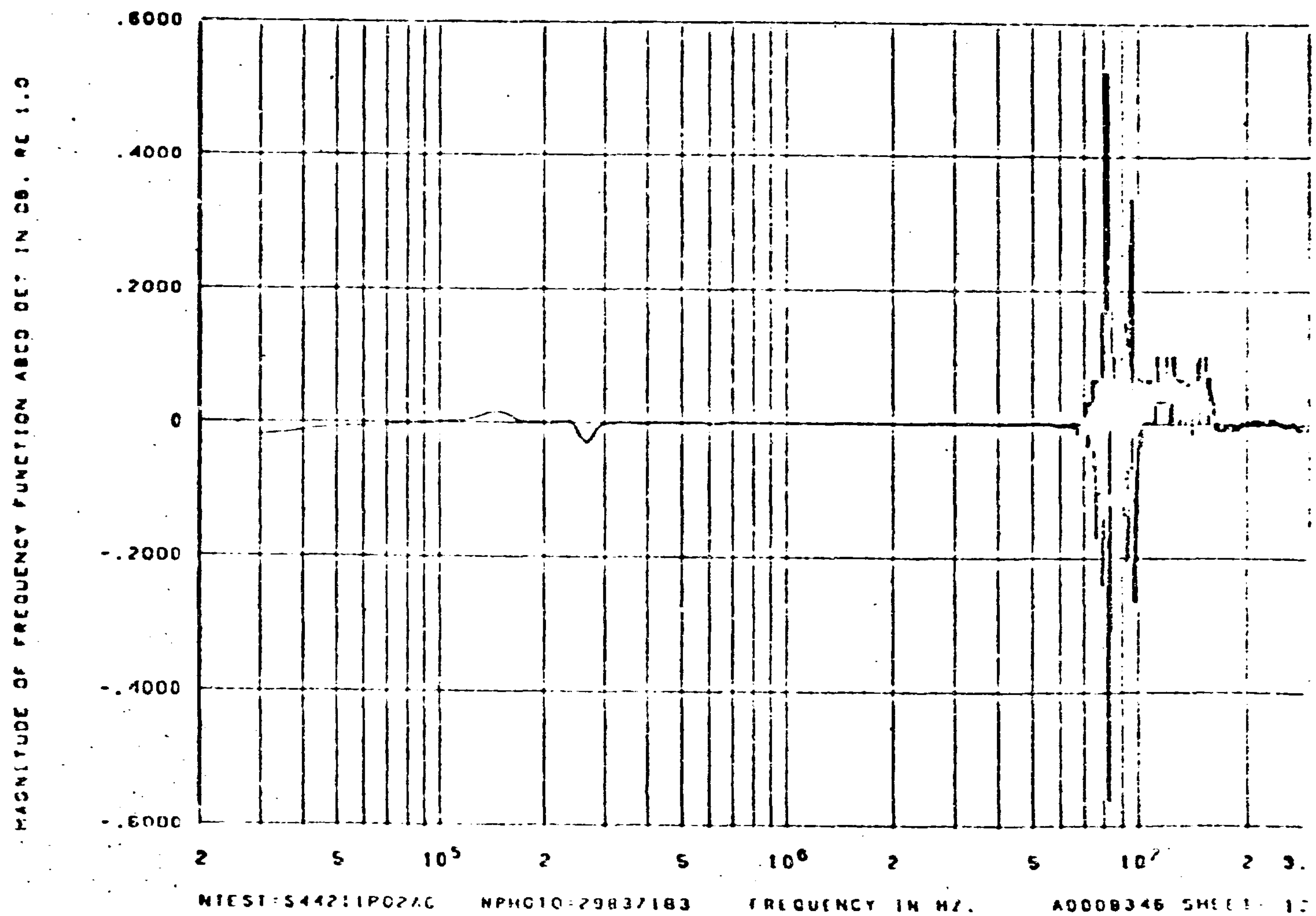


FIGURE 136. TF12 ABCD DETERMINANT MAGNITUDE

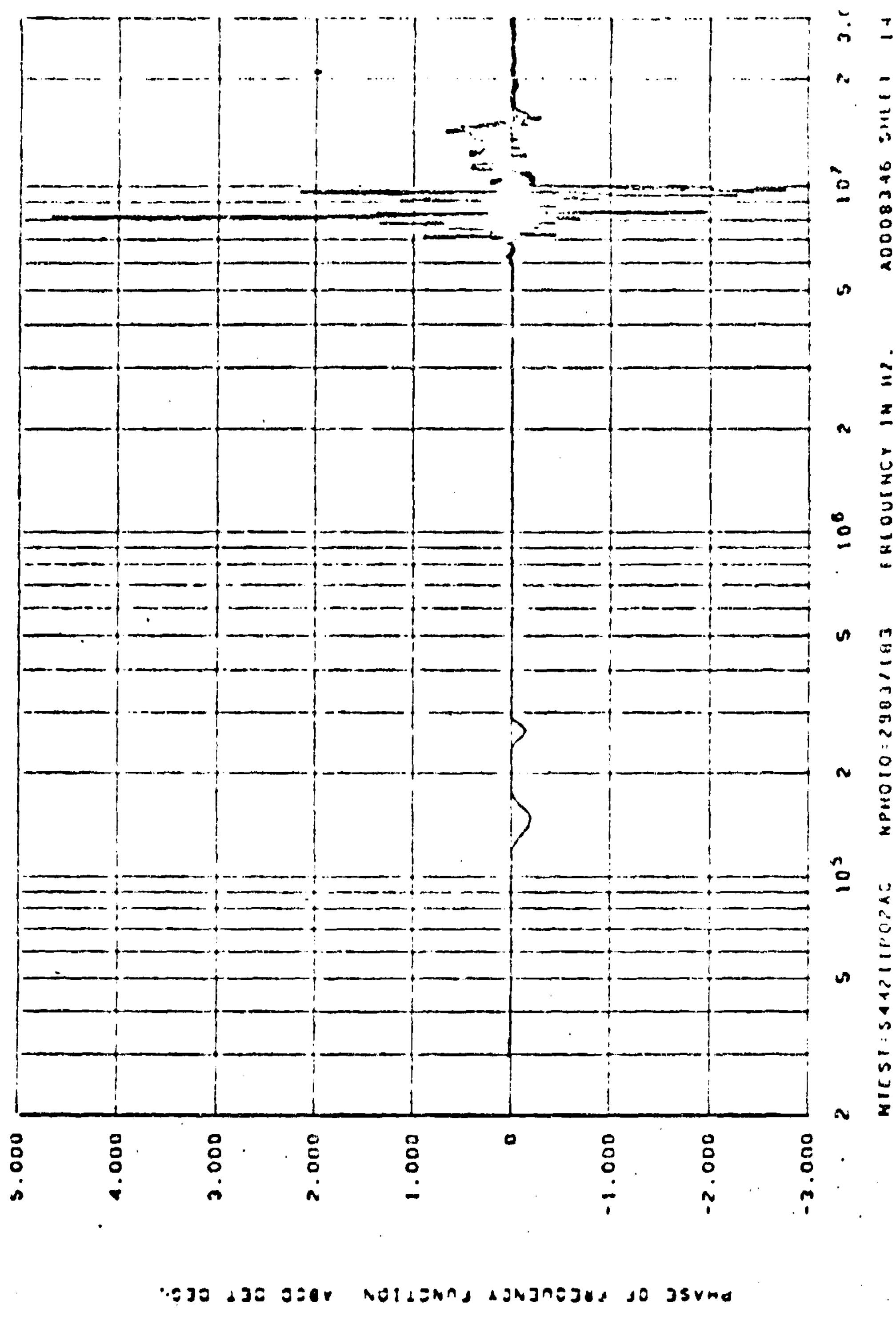


FIGURE 137. TF12 ABCD DETERMINANT PHASE

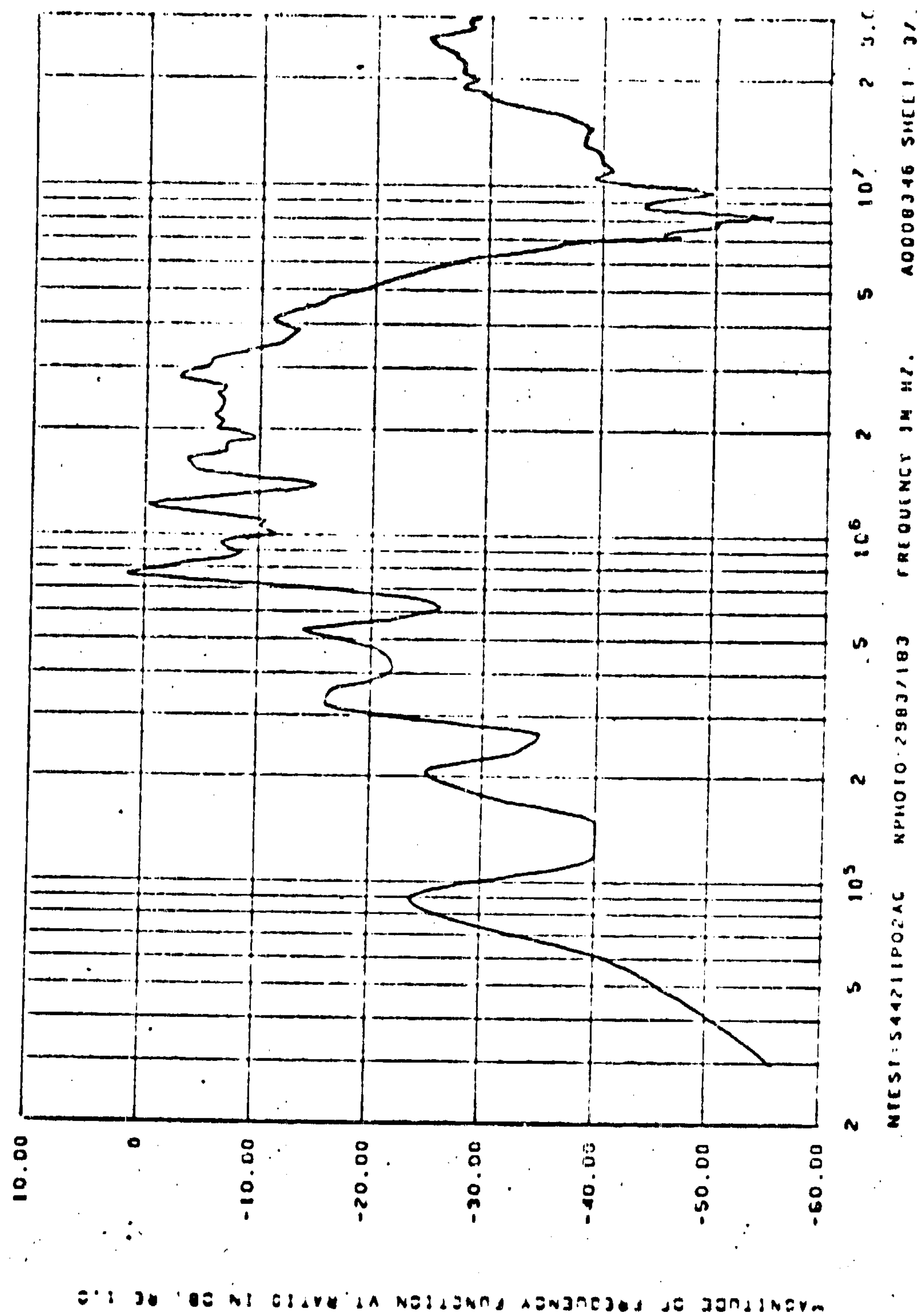


FIGURE 138. TF12 OPEN CIRCUIT VOLTAGE TRANSFER RATIO MAGNITUDE

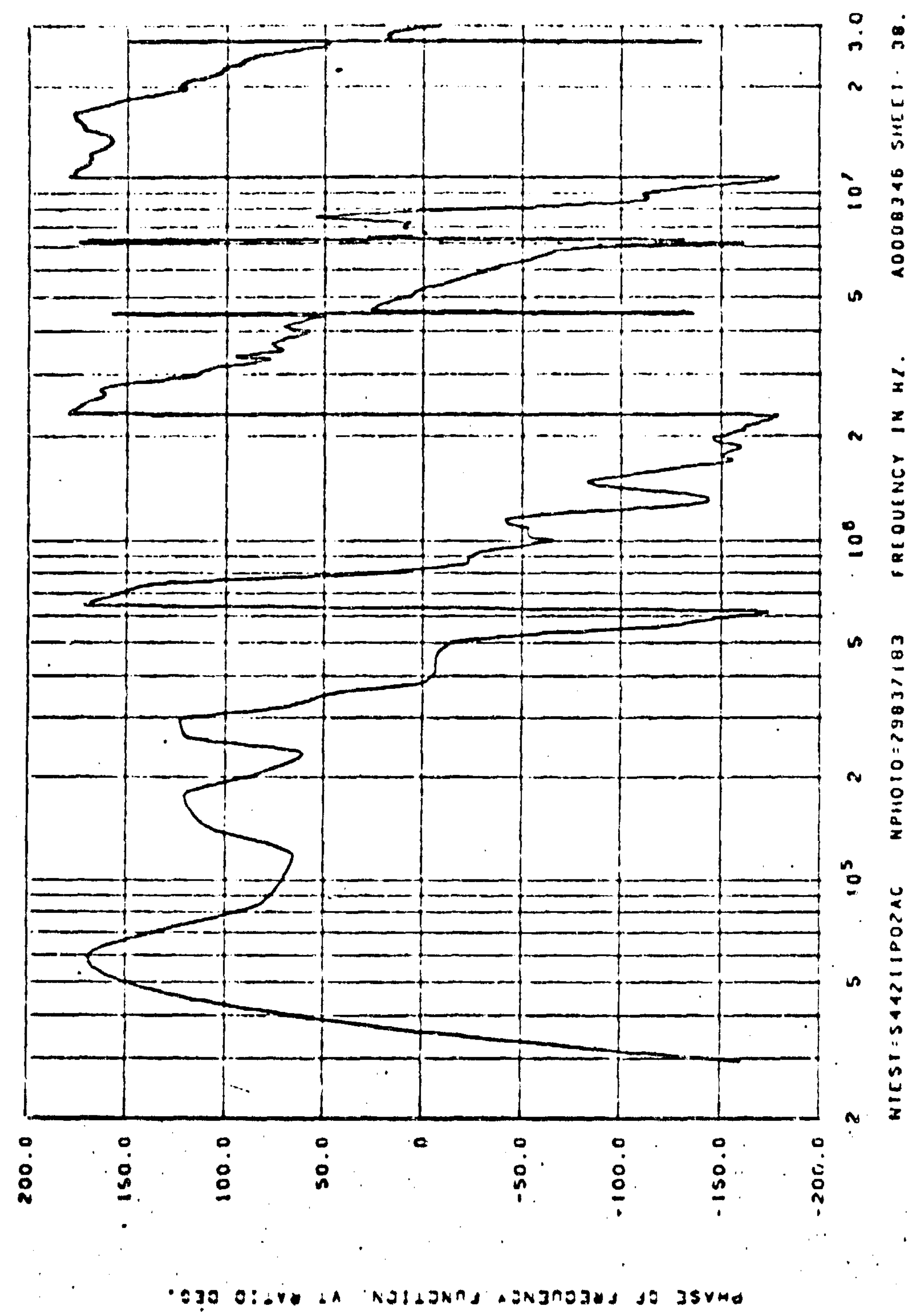


FIGURE 139. TF12 OPEN CIRCUIT VOLTAGE TRANSFER RATIO PHASE

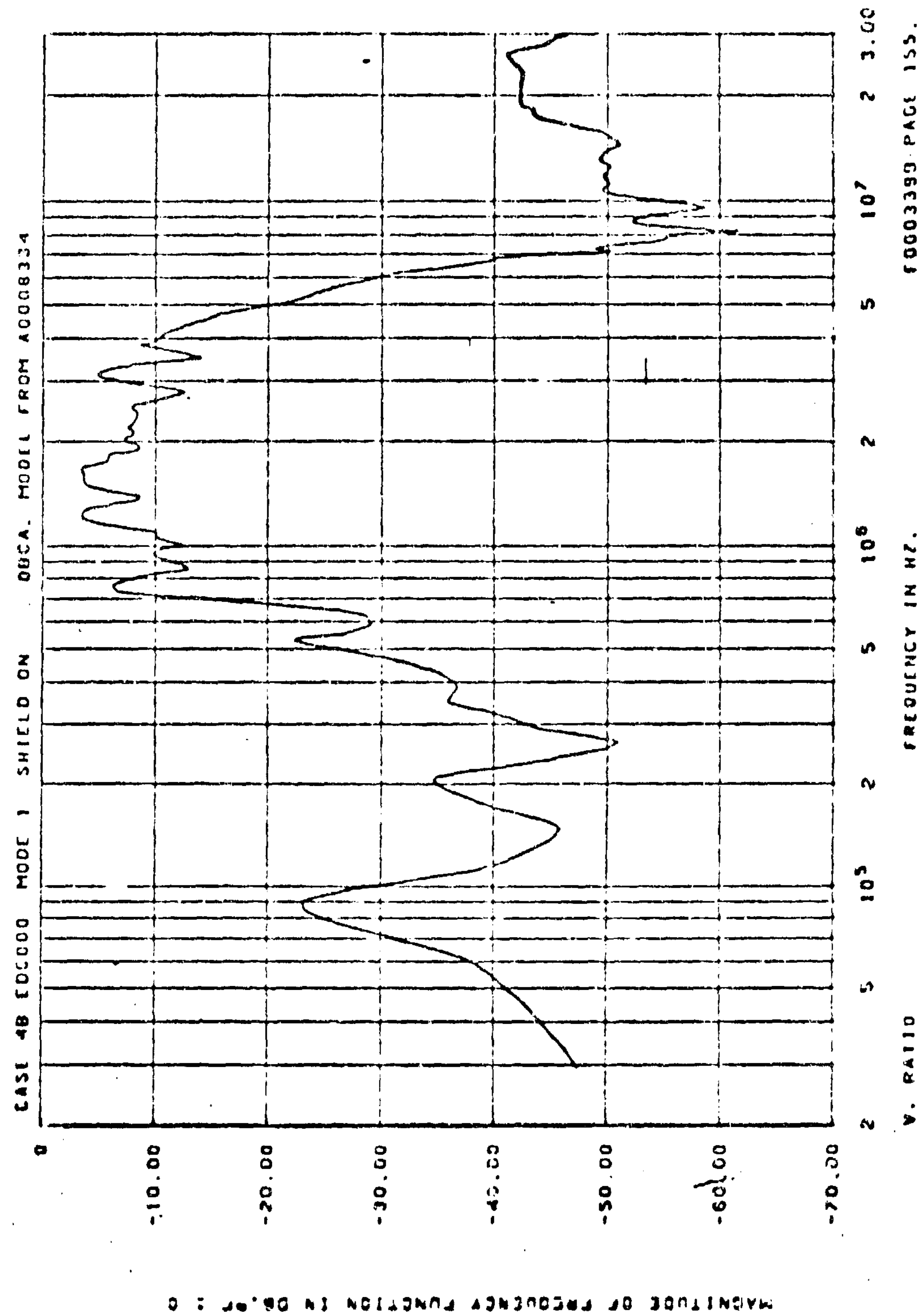


FIGURE 140. TF12 LOADED VOLTAGE TRANSFER RATIO

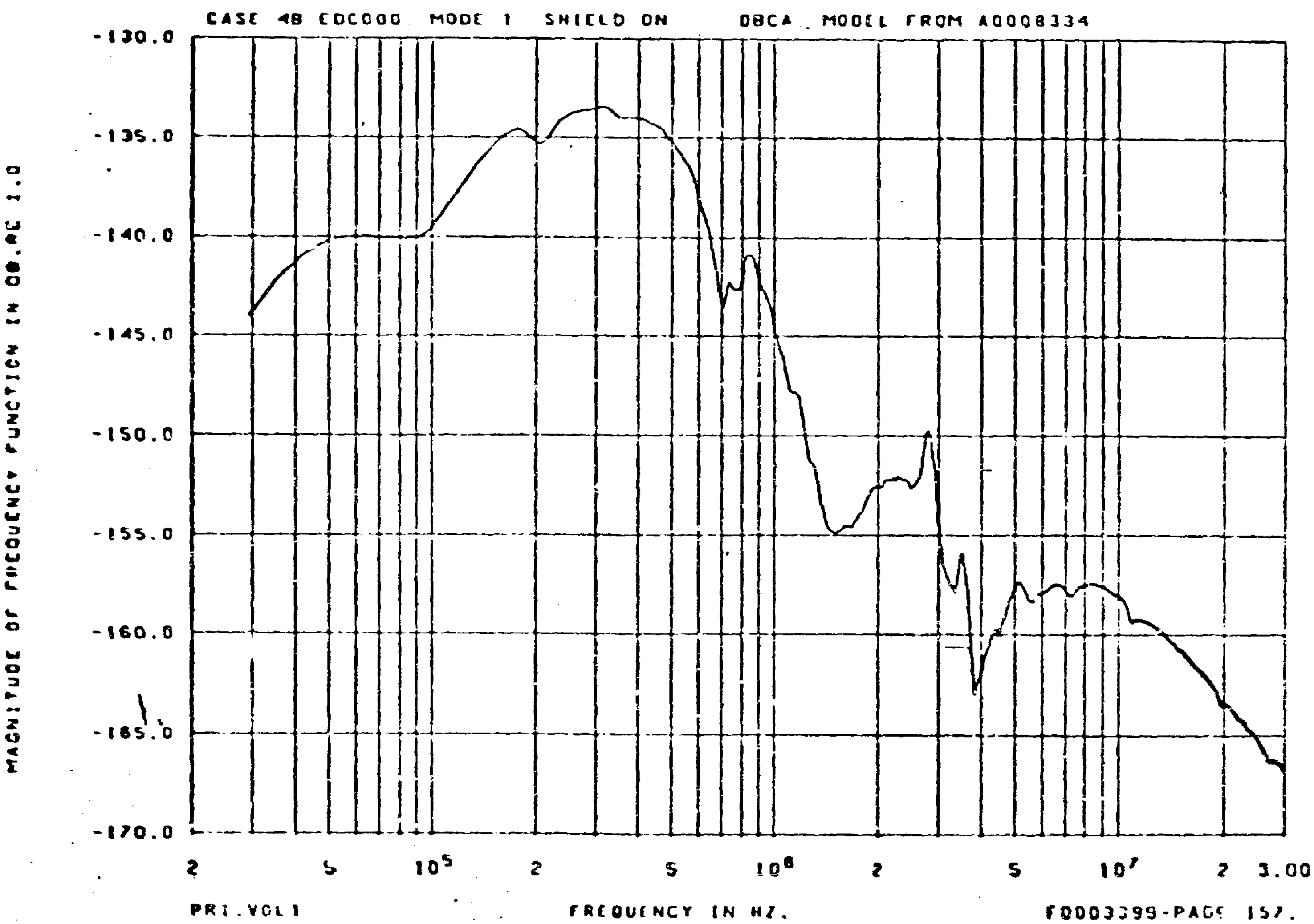


FIGURE 141. TF12 INPUT (Y) PULSE SPECTRUM (P5)

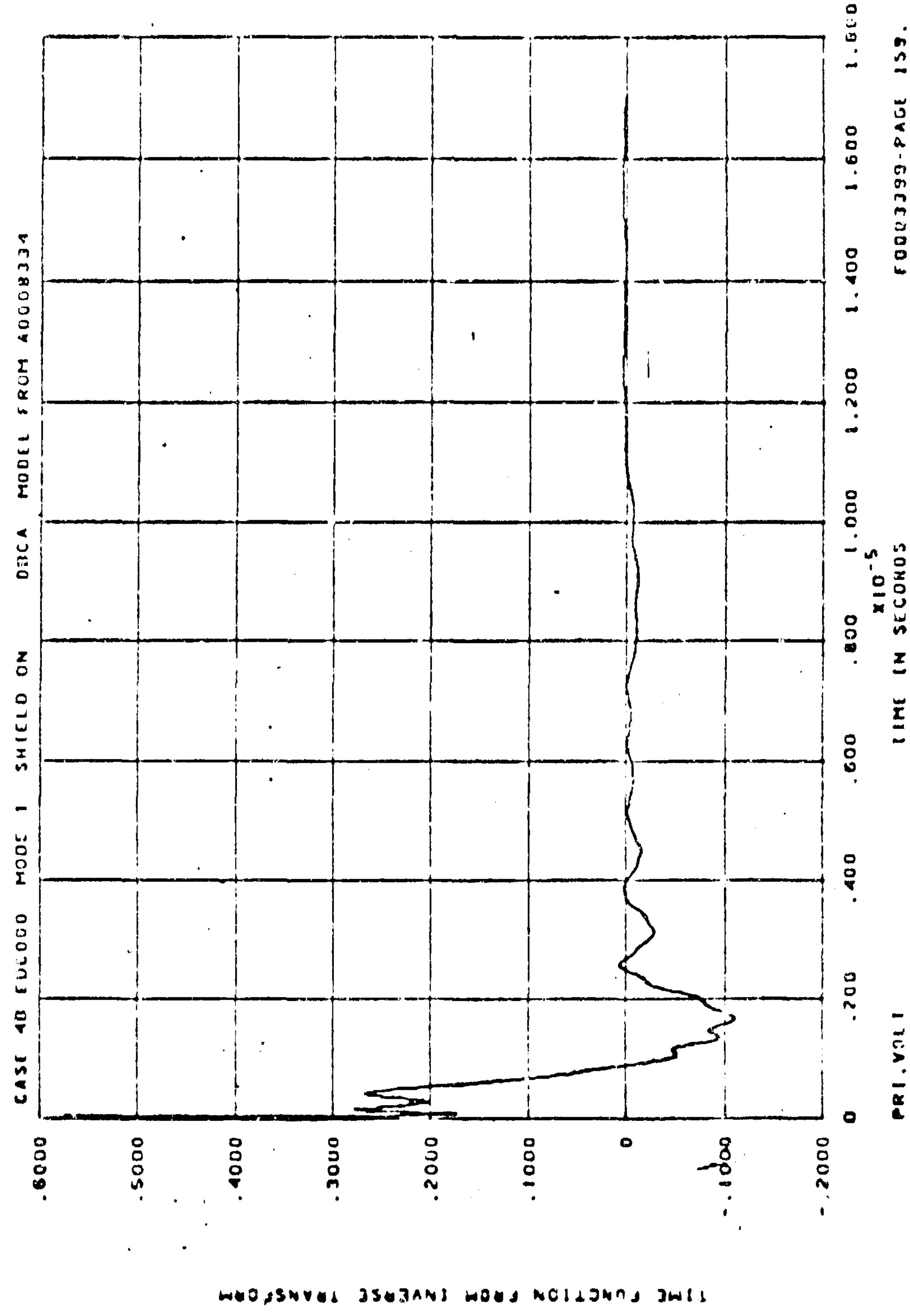


FIGURE 142. TF12 INPUT (Y) PULSE AMPLITUDE

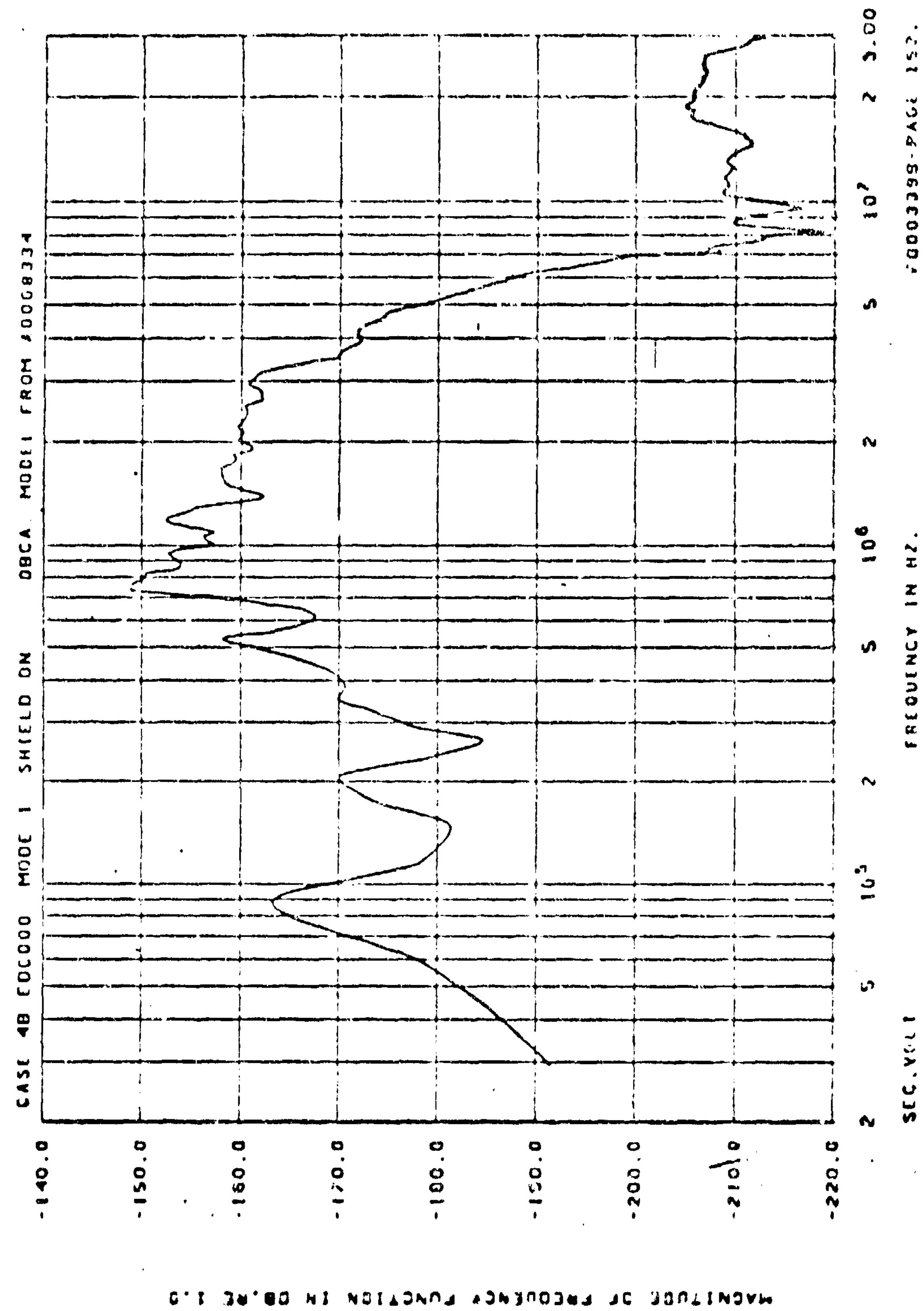


FIGURE 143. TF12 OUTPUT (A) PULSE SPECTRUM

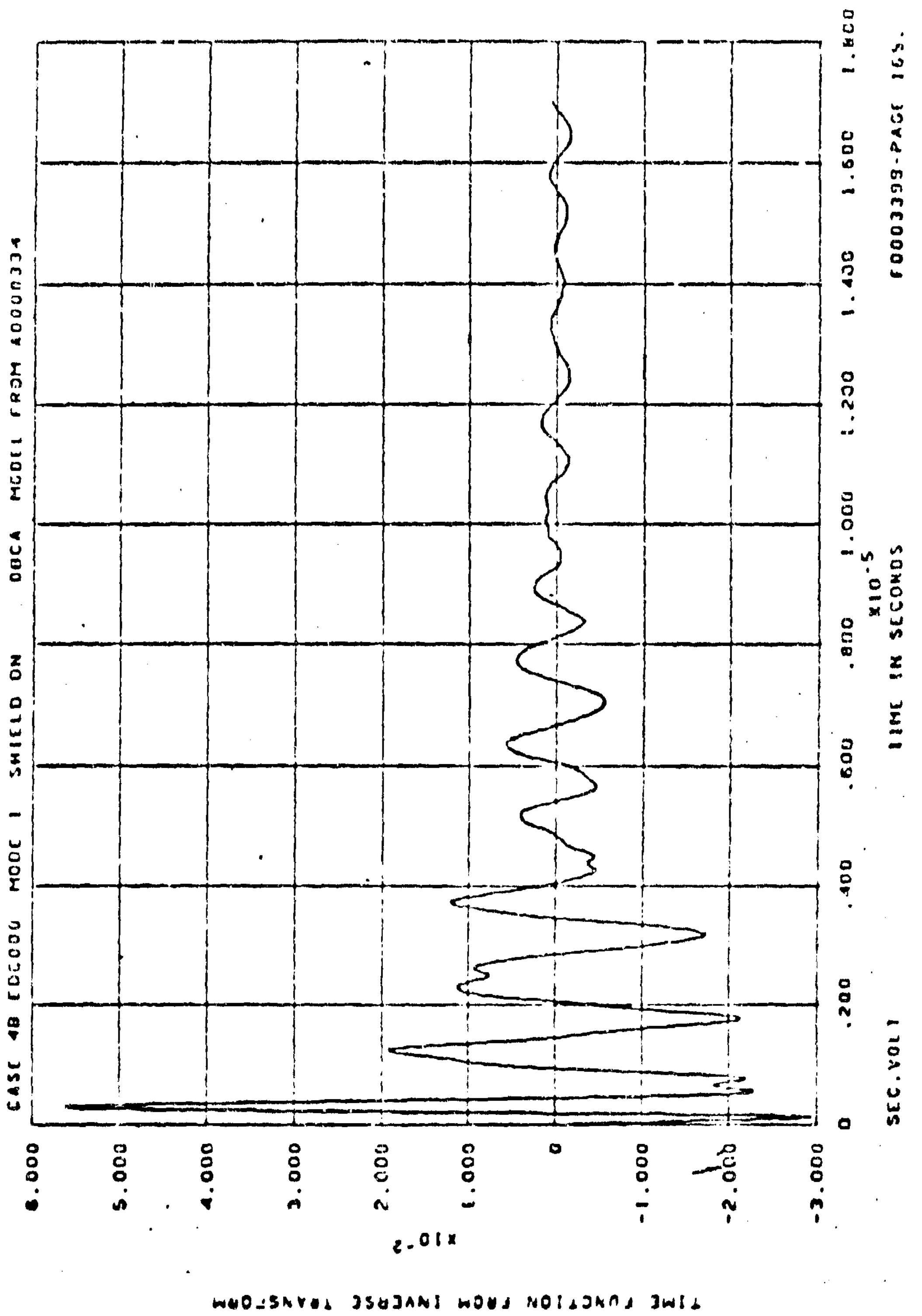


FIGURE 144. TF12 OUTPUT (:) PULSE AMPLITUDE